STRATEGY RESEARCH PROJECT

SIMULTANEOUS STRENGTH AND ENDURANCE TRAINING

BY

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ABSTRACT

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The purpose of this study is to identify the exact workouts required to simultaneously achieve optimum improvement in 1Repetition Maximum (RM) strength, muscle endurance and cardiovascular endurance. The first section identifies the physiological adaptations to each type of training, and using these, the second and third sections identify the optimum application of the acute variables to a periodized training program. The fourth section reviews studies done to date on simultaneous strength and endurance training and identifies how to apply that research to an optimum solution. The fifth section or conclusion presents a combined training program periodizing both strength and cardiovascular workouts using 4-week mesocycles inside a 12-16 week macrocycle. The sixth section identifies the application of this solution on a limited amount of training time.

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SECTION I: EXERCISE PHYSIOLOGY

"If an athlete could run aerobically without sacrificing muscle fibers for blood vessels and if slow twitch fibers could be persuaded to contract as fast and with as much power output as fast twitch-oxidative fibers, the 10K race would be won in about 17 minutes."[1]

1. FUEL SOURCES

a. ATP Fuels all Muscle Contractions

The production of energy in muscles involves the break down of fuel (carbohydrates and fats) in the presence of oxygen by the mitochondria in the muscles to produce adenosine tri-phosphate (ATP). For the energy in foods to be used, it must first be converted into ATP. This conversion, the oxidation or glycolysis of fuels such as glucose and fat is known as cellar respiration and occurs in every living thing from bacteria to humans.[2]

ATP is the universal energy intermediate in cellular biology. When the ATP content of a cell falls below about 50-60% the cell will probably die, thus the production of ATP must keep pace with its usage.

Each time a sprinter takes a stride something like 1×10^{18} molecules of ATP are converted into ADP.[3] This means that a marathon runner must have something like 75 kilograms of ATP to get through a race. Obviously, this would be hard since most elite marathon runners barely weigh 75 kilograms.

Seventy-five kilograms of ATP are obviously not stored in the body. In fact, the human body has as little as 100g at any given time. [4] As soon as an ATP molecule is used for energy, the body makes more. Luckily, the body has several different energy-producing reactions, all of which generate the same intermediate, ATP. These energy

pathways provide critical insight into the types and amounts of training that an athlete can and should conduct.

ATP undergoes a chemical reaction with water to split into one molecule of adenosine di-phosphate (ADP) and one of phosphate. The catalysts that enable this chemical reaction are the oxidative enzymes in the muscle cell. The energy produced is enough to bend a cross bridge linking the thick and thin filaments within the myofibril. If enough cross bridges bend, the filaments slide over each other and if enough filaments slide, the muscle contracts.

b. The Body Stores Fuel for ATP Production in Several Ways

In their book, "Keep on Running; The Science of Training and Performance", Eric Newsholme et al. describe the perfect fuel storage tank for the human body. [5] Ideally, it would have the following characteristics:

* A high chemical energy content, so that energy can be stored without being too heavy.

* Chemical Stability so it does not break down before needed.

* Capacity for rapid mobilization

* Ability to generate ATP without production of toxic end-products

* High molecular weight or insolubility to avoid osmotic complications (i.e. the movement of water in or out of a cell in response to a change in the concentration of dissolved materials in the cell).

Unfortunately, no single source of energy for ATP scores highly in all of the criteria listed above. The body's solution therefore, is store more than one kind of fuel and switch from one to another as circumstance change.

There are three important fuel storage sources in the body: glycogen (carbohydrate), triglyceride (fat) and phosphocreatine (phosphagen). [6] (To a lesser degree, protein or more specifically amino acids can also be used as a fuel source since the liver can manufacture glucose using amino acids).[7] Each has a role to play in the athlete's energy usage.

Fuel is stored in the muscles and liver as glycogen (carbohydrate) and fat cells or in the blood stream as triglycerides. The body can store a very large amount of fat, but the supply of glycogen is limited. In addition, a substance called phosphocreatine is stored in the muscles for immediate use before aerobic metabolism has had a chance to begin. Phosphocreatine is already present in muscles and requires only one reaction to form ATP, but is depleted very quickly.

As early as 1934, scientists knew that carbohydrates are the body's preferred fuels for distance running.[8] The body uses a mixture of carbohydrates and stored fat as fuel sources to produce ATP, but the oxidation of fat requires oxygen so when you increase the intensity of exercise, significantly more demands are made on muscle glycogen and blood glucose than on stored body fat. During exercise, the body will switch to the fuel source that it can best use given the supply of oxygen. That is why when exercise intensity is low, the body burns fat and when you turn up the intensity, the body switches to carbohydrates.

As you begin exercising, muscle glycogen is the primary source of energy. In his book, "Inside Running", David Costill demonstrates the change in muscle glycogen content of a runners' gastrocnemius muscle during three hours of treadmill running, at the runner's best marathon pace. Although the test was run at a constant pace, the rate

of muscle glycogen use in the calf muscle was greatest in the first 90 minutes. Thereafter, the amount of glycogen in the muscle approached zero. As the muscle glycogen approached zero, the runner became severely fatigued.

c. Energy Systems

The body can use glycogen, fatty acids, phosphocreatine or even protein in certain circumstances for ATP production. The significance of this is that there are five major options for fueling the production of ATP in the muscle:

1. Phosphocreatine(CP): stored in the muscle
2. Aerobic Glycolysis: using glycogen stored in the muscles or glycogen created from blood glucose
3. Aerobic Oxidation: using glycogen created from fatty acids
4. Anaerobic Glycolysis: using glycogen without the presence of oxygen.
5. Lactic Acid

d. Phosphocreatine

Glycogen stores in the muscles take about 25 seconds to become available as ATP. Something else has to supply fuel before glycogen can kick in. phosphocreatine is used for this maximum power output, when glycolysis cannot occur rapidly enough to supply sufficient ATP. At the beginning of any exertion, regardless of intensity the first source of fuel is phosphocreatine, until aerobic metabolism can begin production.

To generate ATP from phosphocreatine and ADP requires only one reaction and since phosphocreatine is stored in the muscles and ready for instant use it is by far the fastest source of ATP.[9] The CP system can supply energy for 6-8 seconds; thus, the supply of phosphocreatine in the muscles is quickly exhausted. The body quickly recovers its stores of phosphocreatine after usage. After 22 seconds, the body has replaced about half of that used and after 44 seconds, about 75% have been replaced.

e. Aerobic Glycolysis

Aerobic metabolism as noted above can use fatty acid or glycogen for fuel. Since the stores of glycogen are limited and the stores of fats are essentially unlimited, the two systems work simultaneously, but the proportional share of fuels varies based on the intensity of the exercise and the level of conditioning of the runner.

Glycogen is a carbohydrate made up of thousands of glucose units polymerized into a gigantic tree-like molecule. The significance of the structure is that large amounts of glucose can be rapidly released from the branches of the tree. The muscles and liver use this glucose to build glycogen.[10] Glycogen is stored in the muscles. To produce ATP, glycogen is broken down into glucose by the enzyme phosphorylase and enters the ATP cycle within about 25 seconds of exertion.

Glycogen, however is not an ideal storage fuel. The actual amount of glycogen in the body is limited. A normal human body can hold up to 500g of glycogen in the muscles. (The remaining 100g or so of glycogen in the body is stored in the liver and used to supply tissues that cannot use other fuels like the brain, thus cannot be used safely).[11] The attached water is nearly 1500g, thus adding 3 lb. of body weight. The biological significance of this is that if a human stored all of his fuel reserve as glycogen, vice fat, he would weigh twice as much![12]

In addition, the energy content of glycogen is 16 kJ/g or less than half that of fat. A more significant comparison is that aerobic glycolysis can produce 36 molecules of ATP for each molecule of glucose used.[13] This is 12 times less than that of fat. Secondly, pure glycogen is not found in the cells. Glycogen granules in muscle cells contain water and proteins that must be broken down with chemical reactions.

During simulated marathon running, elite marathoners consume about 5g per minute. With the 500grams stored in the muscles, a runner can carry enough to last about 100 minutes. Since the world record for the marathon is longer than 100 minutes, another fuel source must assist.

f. Aerobic Oxidation

Aerobic oxidation, the use of triglycerides as a fuel can provide 441 molecules of ATP for every molecule of glucose.[14] Triglyceride molecules consist of a glycerol unit and three fatty acid units. These fatty acids provide the chemical energy for muscles. Since most fat is stored in, adipose cells vice in the muscle it must be transported through the bloodstream to be used by working muscles.

Triglyceride molecules react with water through the enzyme lipase to produce glycerol and three fatty acid molecules. Although the fatty acid molecules can pass into the blood, they are insoluble in water or blood plasma. To pass through the blood these fatty acids attach to the protein albumin and are oxidized in the muscles to begin the ATP cycle.[15]

The triglycerides stored in the body have energy content of 35kJ/g, more than twice that of glycogen.[16] Triglycerides are stored dry and thus are by far the most efficient fuel in the body. By way of comparison, aerobic oxidation, the use of fatty acid as a fuel can produce 441 molecules of ATP for every molecule of glucose, 220 time that of anaerobic glycolysis and 12 times that of aerobic glycolysis. [17]

A 70kg male will normally store 8kg of fat and an average woman of 60kg, nearly twice as much. This means that the average man could run non-stop for 3 days and nights at an elite marathoner's pace without the need for food. Obviously, this is not

possible. The problem is that fat cannot be used by the muscle fast enough to sustain the pace. The reason is that fat cells are not soluble in water so to be carried in the blood they must be combined with protein thus requiring additional chemical reactions to become ATP [18]

g. Anaerobic Metabolism

There is enough ATP in a human leg muscle to support about 1 second of sprinting. Without oxygen almost none of the energy released in the breakdown of carbohydrates or fat could be used to create ATP. ATP can, however, be made without oxygen, or anaerobically.[19]

Anaerobically creating ATP is not easy. First, only glycogen can be used in the process. Fat cannot be broken down unless oxygen is present. Obviously, there is a lot less available glycogen in the human body than fat.

The second problem is that anaerobically, the body can produce only a small fraction of the ATP that it can aerobically. A glucose unit of glycogen can provide only 2-3 molecules of ATP anaerobically, compared to 36-37 molecules from aerobic glycolysis. In their book on the science of training, Newsholme, et al. Sited a study which compared the percentage of stored glycogen used through aerobic processes vice that of the anaerobic process for various track events. In a 5K race, although the anaerobic pathway contributed only 13% of the ATP produced, it used 46% of the glycogen depleted in the race.[20]

The third problem with anaerobic metabolism is the accumulation of waste products. There are several by-products of anaerobic metabolism, but the most significant one is lactic acid. The accumulation of lactic acid in a working muscle

decreases its pH to a point where ultimately all of its enzymes would cease functioning and the cells would die. Fatigue is the safety valve that prevents lactic acid from building to this point. We simply slow down as our bodies catch up with lactic acid removal.[21]

h. Lactic Acid

As a runner approaches the top end of aerobic capacity, anaerobic metabolism becomes increasingly important. In the initial minutes of aerobic exercise, oxygen consumption rises rapidly. If the energy demands can be met aerobically, oxygen consumption climbs to a plateau and stays at this plateau, often called steady state.

Steady state reflects equilibrium between energy demands and the rate of aerobic ATP production.[22] Little lactic acid accumulates at steady state. When oxygen consumption reaches a point where it does not rise, despite ever-increasing workload this is known as your VO_2 max. Since the workload is certainly increasing, the additional energy demands must be met somehow. Above your $VO^{2\ max}$, energy demands must be met through anaerobic metabolism.

The reason is called the lactate threshold. As you increase the pace, anaerobic metabolism takes on an increasingly higher percentage of energy production until, at some point the accumulation of lactate in the muscles causes you to stop or slow. The accumulation of 4 mmol / liter of lactic acid in the blood has been termed the onset of blood lactic acid (OBLA). OBLA is one of the key factors that limit running pace.

The body uses part of lactic acid for fuel. It separates lactic acid into hydrogen ions and lactate. It is actually the hydrogen ions that increase acidity in the muscles and cause the “lactic acid burn”. Lactate is used for fuel. In fact muscles, the liver, the

kidneys, the heart and even the brain can metabolize lactate. Sixty percent of accumulated lactate is metabolized for fuel. Most of the remaining forty percent is converted to glucose and protein. Only a small portion is excreted in the urine.[23]

The half-life of the lactaid portion of the by-products of anaerobic metabolism is about 25 minutes. Ninety five percent is removed in 1 hour and 15 minutes.

2. TYPES OF MUSCLE FIBER

Inside a human muscle (excluding the heart) there are two types of muscle fibers. The thicker the muscle, the more myofibrils it contains and the greater is its capability to generate force. The thinner the muscle, the more oxidative enzymes, mitochondria and capillary density it contains.

a. Type 1 Fibers.

Type 1 fibers are the thin type. They are often labeled red or slow twitch fibers when looked at with a microscope. Type I fibers look red due to the higher capillary density and oxidative capability. They are relatively slow to contract with relatively little force but they can continue to contract for a relatively long time. Given these characteristics, they are obviously designed for efficient use of oxygen to produce ATP. Elite distance runners have been found to have a predominance of type 1 fibers.[24] Type 1 fibers contain the highest density of mitochondria (those cells within muscles that produce energy aerobically from glycogen). They have a much greater capillary density, higher levels of oxidative enzymes and large intra-muscular triglyceride stores.[25] All of these factors mean a greater oxygen flow to the muscle and better waste removal capability. Type 1 fibers have been shown to experience significant improvement in aerobic function with aerobic training. [26]

A type 1C fiber has recently been identified. There are very few of these fibers and they are less oxidative than normal type 1 fibers. There is some evidence that with resistance training, type 1 fibers may become 1C fibers, taking on some of the characteristics of type 2 fibers.[27]

b. Type 2 Fibers.

Type 2 fibers are often called fast-twitch or white fibers. They are relatively fast to contract with relatively high force but they only continue to contract for a relatively short time. Given these characteristics, they are obviously designed for generation of force. These fibers have high levels of the enzymes that break down ATP and release energy for the shortening of muscle fibers to produce force. Type 2 fibers have a low ability for aerobic work, as evidenced by their low capillary density, low intra-muscular stores of triglyceride, low mitochondria density and low levels of oxidative enzymes. Since these fibers rely predominantly on anaerobic metabolism and have a poor ability to supply ATP aerobically, they are very susceptible to fatigue.[28]

There is recent evidence that type 2B fibers may be just a pool of unused fibers with low oxidative capability that begin a transformation to type 2A fiber type on recruitment. This is supported by the fact that they are the last to be recruited and observed dramatic reductions of type 2B fibers with heavy resistance training.[29] There are also reports of a type 2C fiber. There are relatively few of these in humans (less than 5%). They are more oxidative than type 2A or 2B fibers. With aerobic training, these may take on the characteristics of type 1 fibers. Type 2AB fibers, also recently identified, represent a combination of type 2A and 2B fibers and are transitional fibers.

Thus, a fiber might be transformed from 2B to 2AB to 2A because of heavy resistance exercise.[30]

Fast twitch or type 2 motor units have more muscle fibers for each motor neuron; thus, they can simultaneously fire more muscle fibers than slow twitch motor units.

c. Fiber Transformation

Although a number of studies indicate that there may be fiber transformation between the type 1 and type 2 fibers, more recent evidence indicates that the changes occur only within the subtypes (e.g. 2B-2AB-2C). The significance of this is that it appears that fiber transformations may occur along a continuum of fiber sub-types based on the intensity, duration and type of exercise.[31] This concept is critical to the design of simultaneous aerobics and strength training programs. All muscle fibers respond to endurance training by increasing their capacity for energy production. This means that type 2A and even type 2B fibers can take on greater oxidative capability (or become 2C fibers). All muscle fibers also respond to resistance training (lifting weights or running hills for instance) by growing larger and increasing their capacity to produce force.

3. CENTRAL NERVOUS SYSTEM

a. Motor Units.

A single nerve fiber controls as few as 5 or as many as 1000 muscle fibers. Each nerve fiber and its attendant muscle fibers are known as a motor unit. The force production of the muscle increases as more motor units fire simultaneously. Resistance training has been proven to increase the synchronous firing of motor units thus increasing the strength of the muscle.

Initial increases in strength are due to increases in the synchronous firing of motor units, or the efficiency of the neuro-muscular system. The neuro-muscular system is "learning a pattern to get stronger. Simultaneously, the antagonist muscle is learning to decrease its neural activity with the training of that particular movement. [32]

b. Motor Unit Recruitment.

When a muscle begins to exercise, not all of the motor units are recruited at once. During slow, low intensity, aerobic exercise type 1 fibers are generating most of the force. As the intensity increases, type 2A fibers are added to the workload. At sprinting speeds, where maximal force production is needed the type 2B fibers are recruited. In running, once the type 2A fibers kick in, you are operating at or slightly below your lactate threshold.[33]

During long distance events like a marathon, as the type 1 fibers become fatigued, the type 2A and eventually the type 2B fibers are recruited, although the pace remains constant.[34] (This may explain the "wall" in a marathon). Since most of the type 1 and type 2A fibers must already be working for the body to recruit type 2B fibers, these fibers are difficult to train.

During resistance training, the type 2A fibers begin to kick in at somewhere around 70% of one repetition maximum in weight lifting.[35] Heavier resistance (e.g., 3-5 RM) requires the recruitment of higher threshold motor units composed of primarily type 2 fibers however, just as in aerobic exercise, the smaller type 1 fibers are recruited first. From a training standpoint, this size order of recruitment is important. In order to recruit type 2 fibers (or more specifically motor units composed mostly of type 2 fibers), the exercise must, be intense.

Recruitment order within a muscle is fixed for a specific movement[36] and changes if the body position is changed. [37] Recruitment order in the quadriceps for instance would be different for the performance of the leg extension and the squat. In their book, "Designing Resistance Training", Fleck and Kraemer hypothesis that variation in recruitment pattern may be one of the factors responsible for the specificity of strength gains. This is evidence that supports anecdotal beliefs long held by strength coaches that to completely develop a particular muscle it must be exercised using several different exercises.[38]

Resistance training builds up the mybrofils in all muscle types, but appears to affect type 2 fibers more than type 1. As the size of the muscle fiber increases, simultaneously the mitochodrial volume and the oxidative enzymes in the muscle are decreasing. [39] At the cellular level, aerobic and strength training cause opposing actions. This balancing act must be overcome if an athlete is to simultaneously train for endurance and strength.

Training cannot change the relative balance of fast twitch and slow twitch fibers (discounting the unproved theory of hyperplasia). This is determined by genetics. Sprinters and power lifters have a higher percentage of type 2 fibers and marathoners have a higher proportion of type 1 fibers. You can, however cause one fiber type to take on the characteristics of the other, based on the training that you conduct.[40]

SECTION II: AEROBIC (ENDURANCE) TRAINING

The goal of this study is to identify the best combination of training to get simultaneous improvement in 1RM strength and middle distance running (3-5 kilometers) or more specifically the 2-mile run. Because the physiological alterations are specific to the type of training, this range is the toughest of the distance continuum. The energy costs of middle distance running include some aerobic and some anaerobic metabolism. Because of this balance, the limiting factors on this training are probably the conversion of fibers and the limits of over-training.

The purpose of this chapter is to first examine the specific energy costs and how specific workouts affect each of these energy systems. The results of this review will indicate how to apply the acute and chronic variables in the design of a cardiovascular training program.

1. ENERGY COSTS CHANGE BASED ON THE TYPE OF EVENT.

The proportion of ATP derived from aerobic metabolism has been extensively catalogued for different distances. The aerobic contribution ranges from less than 5% for a 100-meter sprint to almost 100% for a marathon. For the 5K race, it is about 87% and the 1500-meter it is about 65%. [41] From those figures, we can deduce that during a 2 mile run, the body gets about 76% of its ATP from aerobic metabolism. Since these distances are run at or just below the anaerobic threshold glycogen is the most significant fuel in races from 3k to 5K. However the 25%contribution from anaerobic metabolism is still critical to performance and becomes more critical as a runner approaches the lactate threshold.

In middle distance running, you have a combination of high intensity and relatively long duration. Neither the aerobic or anaerobic systems can independently provide the energy required.[42] Thus, runs in this range are dependent on the simultaneous contribution of both aerobic and anaerobic metabolism. In fact, the systems are not mutually exclusive, as both can contribute simultaneously. The percentage of contribution changes not only for the distance run, but also by the physiological ability of the runners involved.[43]

2. MEASURING ACTIVATION OF ENERGY SYSTEMS.

How do you predict when an energy system kicks in? Each type of training (or training zone) has a specific purpose for optimizing one or more of the physiological factors that impact running performance (fiber type and the energy pathways). To stress a certain energy pathways or a certain type of muscle fibers you must train at a specific intensity for a specific amount of time with a specific amount of recovery. This has been shown to help you train optimally and gradually improve race performance.[44]

If you were to build to a steady pace and maintain that pace, the energy pathways would begin to contribute in the following sequence: Stored ATP and phosphocreatine are the primary energy sources for the first 25 seconds of a run until the muscle can begin aerobic glycolysis. At about 30 seconds until about 3 minutes, aerobic glycolysis is the primary energy system, using stored muscle glycogen until the body can deliver glycogen and stored triglycerides through the blood to the muscle. After about 3 minutes, the blood is delivering glycogen from the blood. At about 10

minutes, aerobic oxidation begins to contribute; starting to burn stored fat as a fuel that begins to be the primary fuel source after about 15-20 minutes.

There are several physiological variables an athlete can monitor to identify when the body has shifted to the various energy systems. The two most common are VO2max and Lactate Threshold.

a. VO2max

The physiological variable that best describes the capability of the cardiorespiratory system to transport oxygen to the muscles for generation of ATP is VO2max. Because 76% of the 2-mile run is fueled by aerobic metabolism, VO2max is important to performance. Values for VO2max average from 40 to 50 milliliters / kilogram / minute (ml/kg/min) to 94 ml/kg/min for elite cross-country skiers. Average values in elite middle distance runners range from 68 to about 77 ml/kg/min. Average values in elite long distance runners average from 75-85 ml/kg/min.[45]

Middle distance runners have generally lower VO2max than long distance runners but compete at a higher percentage of that VO2max and incur a greater energy cost for distance run. The correlation between middle distance performance and VO2max is generally lower than the correlation between long distance running and VO2max. Brandon and Boileau found that the correlation of VO2max and performance was a more important predictor of 10K races than shorter distances.[46]

b. Lactate Threshold

The running pace that most people can sustain is not nearly at their $VO^{2\ max}$. As you increase the pace, anaerobic metabolism takes on an increasingly higher percentage of energy production until, at some point the accumulation of lactate in the

muscles causes you to stop or slow. The accumulation of 4 mmol / liter of lactic acid in the blood has been termed the onset of blood lactic acid (OBLA). OBLA is one of the key factors that limit running pace. The body can no longer buffer the acid in the blood and muscles as fast as it is being produced.

The pace at which excess lactate begins to accumulate has been defined as the anaerobic threshold (AT).[47] The heart rate at which this generally is about 85% of maximum heart rate. The anaerobic threshold is, however different for every runner. To compound the problem, there is not a direct or linear correlation between percentage of maximum heart rate and percentage of VO2max. Science dictates that we train at a given percentage of VO2max, but it would be hard to measure VO2max outside of a laboratory.

There is, however, a direct and linear correlation between the percentage of reserve heart rate and the percentage of reserve VO2max. The reserve heart rate and reserve VO2max are the differences between the maximum value for an individual and the value for that individual at complete rest. This is the reason that the Karnoven method of determining training heart rate zones is significantly more effective.[48] You simply subtract your resting heart rate from your maximum heart rate, calculate the percentage of the difference at which you wish to train (e. g. 60% for longer runs) and add the resting heart rate back to that percentage.

The anaerobic threshold (AT) is considered a good estimation of the pace that a runner can maintain during a longer race. Maffulli, et al. evaluated 112 endurance athletes for run speed over 800m, 1500m, 3000m 5000m and 10,000m. They concluded that there was a high correlation between the run performance and the AT

for races of 5000m and above. There was no significant correlation between AT and race performance at 800m or less.[49]

3. ACUTE VARIABLES

Acute variables define all possible conditions within a single training session. In cardiovascular training, the acute variables are frequency, intensity, duration, and rest periods between intervals and periods of exercise.

By varying the acute variables, each workout targets a specific energy system. To get the optimum results from a workout, each workout must have a specific purpose targeting a specific aspect of cardiovascular performance. "Junk miles" or running the same pace and same distance each workout would be grossly ineffective for anything except general fitness and health.

Planned manipulation of these acute variables causes significant changes in physiological adaptations to the workout. Although the percentage is specific to the event, all middle distance events derive a small portion of their energy needs from phosphocreatine, a moderate portion from anaerobic glycolysis and the largest portion from aerobic glycolysis. The lactate removal system is also significant to middle distance races. Planned variation of the acute variables based on the specific energy costs of a given event allows coaches to design cardiovascular training programs.

a. Frequency

How often should you train? In 1998, the American College of Sports Medicine (ACSM) recommended a frequency of 3-5 days per week in order to maintain cardiorespiratory health and fitness in adults.[50] These guidelines are not intended for athletic performance, but the maintenance of health. Interestingly, their 1998

recommendations on frequency stated that the ACSM "now views exercise/physical activity for health and fitness in the context of an exercise dose continuum... programs involving higher intensities and/or greater frequency/duration provide additional benefits". [51]

The current guidelines are similar to those that running have been recommending for several decades. When one reviews various program recommendations for 5-K race performance the frequency of training is amazingly consistent (See Table II-1). The significance of all of these recommendations, including ACSM, is that cardiovascular improvement for competition is best attained by training 5-6 days each week.

Source	**Robinson** [52]*	**Burke** [53]*	**Newsholme** [54]*	**Lawrence** [55]*	**Anderson** [56]*	**McMillan** [57]*
Days/Week	5-6	6	6	6	5-6	5

Table II-1: Frequency of Cardiovascular Training

*Note: Recommends alternating hard and easy days.

b. Duration

Another aspect of frequency is the age-old question of how many miles a week should you run. There appears to be a point of diminishing returns where further increases in weekly mileage fail to increase performance. One study showed that training 40-80 kilometers (24-48 miles) a week elicited significant improvements in VO2max, but greater distances produced only slightly greater increases, but significantly greater incidences of over-use and injury.[58]

Dudley et al Found that longer exercise bouts produce greater increases in mitochodrial density, however there is a point of diminishing returns (see figure 1). After 1 hour the rate of increase drops off , and after 2 hours it drops off significantly. By 3

hours the rate of increase is insignificant. It is important to note that after 1 week of detraining, almost 50% of the increase in mitochodrial content is lost. After 5 weeks all of the adaptations had been lost.[59]

Elite distance athletes have a proven requirement for the marginal additional increases in performance provided by additional mileage. However, the muscle fiber adaptations created by these levels of mileage creates a specific effect and virtually guarantees a significant loss of upper body strength and eventual overuse injuries.

Below is a comparison of recommendations from coaches and running authorities on how much weekly mileage is optimal for novice competitors training for a 5-K race.

Coach / Category	**Glover** 60	**Lawrence** 61	**Anderson** 62	**Collins** 63	**Higdon** 64**	**Burfoot** 65
Weekly Mileage	25-40	35-46	25-35	30	32	30

Table II-2: Weekly Mileage

The significance of these recommendations is that for 5-K performance below the elite level duration of 25-40 miles a week appears to be optimum.

c. Intensity

In a series of studies, Hickson et al had subjects execute identical training programs and then reduced either the duration or the intensity by one thirds or two thirds. They found that it is possible to maintain almost all of the performance (less long-term endurance) increases with up to a two-thirds decrease in duration (from 40minutes to 26 minutes.[66] Their conclusion was that intensity is an essential requirement for maintaining increased aerobic power.[67]

Mitochondria are the cells that aerobically produce ATP in muscles. It is well known that long duration aerobic exercise induces significant increases in mitochondrial

content of muscle fibers. Figure 2 displays improvement in muscle fiber mitochondrial content during running programs of shorter duration. The peak adaptation appears to occur, in shorter runs as the intensity increases with very short intervals at 100% of VO2max producing the greatest improvement. [68]

Different running intensities have been shown to produce different hormonal responses. In 1989, Kraemer et al. studied the hormonal responses to training of 3 different running programs over 10 weeks. [69]

One group (sprint interval- SI) performed sprint intervals on 3 days per week. They did 2 sets of intervals separated by 5 minutes of rest. Each set consisted of 4 (20-second) maximal sprints with one-minute rest intervals. Heart rates were monitored and after the second sprint, subjects were determined to be training at 96% of their directly determined maximal heart rate.

The second group (endurance-E) trained 3 days a week and ran as far as they could in 30 minutes. Heart rate was again monitored and these subjects were determined to be training at a mean exercise intensity of 80.0% of their treadmill VO2max. This is at or slightly above the lactate threshold.

The combined group trained six days a week and performed the workouts of the endurance group and the sprint interval groups on alternating days. Heart rate determinations during exercise showed that they trained at 93.4% of their directly determined maximal heart rate during sprints and 79.7% of treadmill VO2max during the endurance runs.

VO2max improved 6.6% for the sprint group, 18.3% for the endurance group and 14.1% for the combined group. Interestingly, the combined group showed significant

pre to post training reduction in the magnitude of increase of beta-endorphins, lactic acid and cortisol at 5 minutes after workouts.[70] The authors noted that the combined group probably exhibited some over training towards the end of the study, but the significance is that the combined group showed a significant improvement in the ability to flush lactic acid as compared to the other groups.

In 1996, in a pair of studies, Tabata, et al explored the effects of moderate-intensity endurance and high intensity intermittent (interval) training on both anaerobic capacity and VO_{2max}. While the moderate intensity (70% VO2max) exercise improved VO2max, it had no effect on anaerobic capacity. The interval training, however, improved both VO2max and anaerobic capacity, probably through imposing intensive stimuli on both systems.[71]

Each category of intensity corresponds to one of the energy systems and the corresponding aspect of cardiovascular performance. Those five aspects of cardiovascular performance although named differently by different sources are essentially endurance, stamina, speed, sprinting and strength.[72,73,74]

Primary Physiological System	**Type Workout**	**Aspect Improved**
Aerobic Oxidation & Aerobic Glycolysis	Aerobic Conditioning	Endurance
Lactate Removal	Anaerobic Conditioning	Stamina
Anaerobic Glycolysis	Aerobic Capacity	Speed
phosphocreatine	Anaerobic Capacity	Sprinting
Lactate Removal and Muscle Fiber Composition	Strength	Strength

Table II-3: Specific Workouts for Specific Energy Systems

d. Aerobic Conditioning

Aerobic conditioning improves endurance or the body's ability to use oxygen. VO2max is the common measure of the body's ability to use oxygen and is increased by longer runs at relatively slow pace (60-75% of maximum heart rate). These workouts increase the muscles' ability to consume oxygen, increase the capillary density in the working muscles, the amount of mitochondria and the oxidative enzymes in the muscle fibers. They also teach the muscles to use glycogen and fatty acids more efficiently improving aerobic glycolysis and oxidation. In other words, they improve your VO2max.

How much can training affect VO2max. Most studies in the past have indicated that a minimum increase in VO2max of 10-15% can be attained using the ACSM guidelines.[75] Improvement is, however directly related to frequency, duration and intensity.

R. C. Hickson et al showed an improvement of VO2max of 44% (average) over ten weeks induced by training 6 days a week. For 3 days a week, the eight subjects performed 6 5-minute intervals on a bicycle ergometer that elicited VO2max separated by 2-minute intervals of exercise requiring 50-60% of VO2max. On the alternate days, they ran as far as they could in 40 minutes. Four of the Eight subjects achieved VO2max approaching or exceeding 60 ml/kg/min.

K. A. Mikesell and G. A. Dudley repeated this study in 1984 for 5 weeks using seven well conditioned male runners to determine its effect on 10-K run times. The mean run time dropped by over 81 seconds.[76 77] The significance of this study is that it showed VO2max can increase more rapidly and to a greater extent than was previously thought.

Duration of exercise at low intensity has been shown to increase the body's ability to oxidize fat for fuel. Phillips, et al. did a study in 1996 to determine the effects of training duration on substrate turnover and oxidation during exercise. Active, but untrained males trained for 31 days on a bicycle ergometer for 2 hours a day at 60% of pre-training VO2max. Exercise increased the rate of glucose production and utilization. Interestingly, at day 5, the authors noted a training-induced 10% increase in total fat oxidation due primarily to an increase in intramuscular triglyceride oxidation and a decreased glycogen oxidation. By day 31, the total fat oxidation increased a further 58%. The pattern of fat oxidation at day 31 showed a decreased reliance on free fatty acids in the blood and an increased reliance of intramuscular triglyceride.[78] This study supports previous evidence that long-term aerobic conditioning induces a progressive increase in fat utilization and reduction in glucose oxidation.

How far must an athlete run to improve VO2max? Most sources indicate that if an athlete is training for longer races the longest run should be about two-thirds as long (time, not distance) as the intended race, but at a slower pace.[79] For shorter races (10K to 5K), most authors recommend no more than 10-12 miles for a longest run.[80] Table II-4 shows a review of these recommendations.

Coach	**Glover** [81]	**Lawrence** [82]	**Anderson** [83]	**Collins** [84]	**Higdon** [85]**	**Burfoot** [86]
Weekly Mileage	25-40	35-46	25-35	30	32	30
Long Run	8-10	7-10	8-10	8	10	10

Table II-4: Duration of Aerobic Conditioning Workouts

Despite the great improvements in VO2max to be had by longer runs, they pose an imminent danger of over training. To avoid over training, the intensity or pace for

these runs is commonly cited as 55-65% of maximum heart rate or up to 3-minutes slower than marathon pace. In addition, unanimously, coaches and athletes agree that athletes should execute long runs no more frequently than once a week.

Source	Robinson 87*	Burke 88*	Newsholme 89**	Lawrence 90*	Anderson 91*	McMillan 92*
Aerobic Conditioning	2-7 d/w (1 long)	4 d/w (1 long)	3 d/w (1 long)	4 d/w (1 long)	4 d/w (1 long)	3 d/w (1 long)

Table II-5: Frequency of Aerobic Conditioning Workouts

*Note: Recommends alternating hard and easy days.

e. Anaerobic Conditioning

Anaerobic conditioning builds affects stamina. The purpose of anaerobic conditioning is to raise the pace that a runner can sustain at anaerobic threshold. Remember; steady state reflects equilibrium between energy demands and the rate of aerobic ATP production. Little lactic acid accumulates at steady state. Anaerobic threshold is slightly above steady state. Lactic acid begins to accumulate, but not so fast that the athlete cannot hold the intensity. Typically the lactate threshold occurs between 40-85% of VO2max. That pace (anaerobic threshold) occurs at around 85% of maximum heart rate.

The lactate threshold may be the most significant factor in middle distance performance. Robinson and Carrino, in their book Max O2, state: "In fact, the lactate threshold is so significant in determining performance, it's possible for someone with a lower VO2max to have a greater aerobic performance capacity."[93]

In a longitudinal study, Tanaka et al. found significant correlation at every assessment point over nearly 5 months between 10,000m run performance and percentage of VO2max at the AT. They hypothesized that a 20-second improvement in

the 10,000-m race time correlates to a 1-ml/kg/min increase in VO_2 at the AT. The relationship did not change as run performance increased.[94] The significance of this is that raising the percentage of VO2max a runner can hold at the anaerobic threshold has the most direct impact on middle distance performance.

In other words, anaerobic conditioning primarily serves to increase the percentage of VO2max an athlete can sustain at or near the lactate threshold. Additionally, they improve the oxidative capability of type 1 fibers not recruited during aerobic conditioning runs and begin to increase the oxidative capacity of type 2A fibers. Anaerobic Conditioning workouts improve aerobic glycolysis, lactic acid buffering and removal and, to a lesser degree, anaerobic glycolysis. At these increased speeds aerobic oxidation is no longer significant (there is not enough oxygen present to use fat as a fuel source). Lactate threshold can be increased independently of VO2max and can improve 10-20% in response to training.

A significant question to the application of lactate threshold runs is whether to run at or above the LT in training. A study by Joanne Henritze et al from the Human Performance Laboratory of the University of Colorado compared the effects of training at and above lactate threshold. Subjects were randomly assigned to 3 groups for a 12-week training program. One group trained above the lactate threshold, a second group trained at the lactate threshold and the third was a control group. Subjects were assessed for VO2max, VO^{2LT}, and VO2max/VO^{2LT} before and after the study. Training loads were equated so that each subject expended approximately 1465 kJ per training session. This effectively removed training volume as a variable. The study concluded that training above LT produces significant increases in VO^{2LT} (48%) as compared to

training at LT (18%). Interestingly, no significant change was found in VO2max in any group. (5.6% for >LT and .9% for =LT).[95] The significance of this is that is supports other findings that indicate that VO2max at LT can be increased independent of improvements in VO2max. The clear indication is that to improve race pace, you must train above LT.

Anaerobic conditioning workouts typically take the form of cruise intervals, tempo runs or fartlek runs, all of which increase your body's lactate threshold running speed (anaerobic threshold).

Tempo runs are fast continuous runs at 80-85% of maximum heart rate, aiming to run at just below the anaerobic threshold. These runs are typically between 20 and 40 minutes for middle distance runners. Cruise intervals are 800-m to 2-mile repeats at 85% of maximum heart rate with 1-2 minutes in between each interval. Fartlek runs are periods of faster running introduced into slower runs. When used to affect anaerobic conditioning, the pickups are run at about 85% of maximum heart. These are normally used to prepare runners for more demanding aerobic capacity intervals.

Coaches are again consistent on their recommendations for the duration of anaerobic conditioning workouts:

Source	**Robinson** [96]*	**Burke** [97]*	**Lawrence**[98] *	**Anderson** [99]*	**McMillan** [100]*
Tempo Runs	20-40 min	20-40 min	20-40 min	20-40 min	20-40 min
Cruise Intervals	1200m-1 mile	1200m-1 miles	1200m-1 mile	1200m-1 mile	1200m-1 mile

Table II-6: Duration of Anaerobic Conditioning Workouts

Anaerobic conditioning workouts are intense. They require anaerobic metabolism and produce the resulting by-products that the body must flush. As an athlete trains in the anaerobic range too often, overtraining will set in. As a result, most coaches recommend lactate threshold runs only once a week. See table II-7:

Source	Burke 101*	Newsholme 102**	Lawrence 103*	Anderson 104*	McMillan 105*
Anaerobic Conditioning	1 d/w	1 d/w	1 d/w	1 d/w	1 d/w

Table II-7: Frequency of Anaerobic Conditioning Workouts

*Note: Recommends alternating hard and easy days.

f. Aerobic Capacity

Aerobic capacity builds speed. They accomplish this by increasing the body's ability to consume and utilize oxygen at speeds close to the anaerobic threshold and increase the ability to buffer lactic acid and flush it from the system. These type workouts increase not only the lactate buffering of the muscles but of the kidneys, liver and blood. They teach a runner to relax and hold concentration while holding a challenging pace. Holding the pace steady involves not only removing lactic acid from the system, but also learning to tolerate higher concentrations in the blood. These workouts improve the high end of aerobic glycolysis, anaerobic glycolysis and lactic acid removal.

Aerobic capacity workouts are often called intervals. They include intervals lasting from two to six minutes at 90-95% of the maximum heart rate. Recovery jogs between intervals are equal to or longer than the interval. Intervals are one of the three key workouts that form the base of literally every running program currently in publication for

3000-m to 10,000-m. Below are comparisons of coaches' and running authorities' recommendations on percentage of aerobic capacity (greater than 90% of MHR) miles can be run each week.

Source	Glover[106]	Lawrence[107]	Anderson[108]	Collins[109]	Higdon[110]	Burfoot[111]
% of weekly miles	10-20% *	9%	10%	10%	9.3%	7.5%

Table II-8: Duration of Aerobic Capacity Workouts

* Experienced runners preparing for a 10K or less can do 25%.

These workouts are intense and executing them too frequently will cause over training. There is some anecdotal evidence that even once a week may be too often, but coaches remain consistent in their guidelines:

Source	Burke[112]*	Newsholme[113]**	Lawrence[114]*	Anderson[115]*	McMillan[116]*
Aerobic Capacity Intervals	1 d/w	1 d/w	2 d/w	1 d/w	1 d/w

Table II-9: Frequency of Aerobic Capacity Workouts

*Note: Recommends alternating hard and easy days.

g. Anaerobic Capacity

Anaerobic capacity workouts are truly anaerobic work and build sprinting ability. They reach a level of intensity that recruits type 2A and finally type 2B fibers. These workouts will further increase your VO2max and psychologically makes your race pace feel easier. Most importantly anaerobic capacity workouts train the body's ability to produce energy anaerobically by specifically targeting the phosphocreatine system. This energy system fuels true sprints and only lasts up to about 15 seconds.

Most coaches recommend sprints of 50-100m that start at 800m pace and build to top speed with at least two-minute recoveries to replenish the CP system. Because these are very demanding workouts, most authors and coaches recommend relatively few of them, and most only in a peaking phase:

Variable/ Source	**Robinson** 117*	**Burke** 118*	**Newsholme** 119*	**Lawrence** 120*	**Anderson** 121*	**McMillan** 122*
Anaerobic Capacity Intervals	1 d/w to 2 d/ m	0 d/w except peaking	0 d/w except peaking	2 d/m peaking	0 d/w except peaking	1 d/w (peaking) vice AC Intervals

Table II-10: Frequency of Anaerobic Capacity Workouts

h. Strength Runs

These are hill repeats. Anecdotal information would indicate that hill running helps increase the strength or force generation of muscle fibers. In a study at the Department of Kinesiology at University of Waterloo investigators studied the effects of an intense hill running protocol on middle aged (34-37) endurance-trained men. For six weeks, the training program was conducted four times a week. The program consisted of a 3-km warm up run at low intensity followed by 3 maximal runs on a long paved hill of 3.3% grade for 60 seconds each with two minutes of recovery jogging between repeats. Immediately afterwards, the subjects ran 5 sprints of 6 seconds on a grassy 44% grade with 24 seconds recovery and 2 more maximal runs of 90 seconds on the 3.3% grade with 3 minutes of recovery. After running, subjects performed leg presses at 15-RM.

The results were surprising. Significant improvements were noted in training distance for each interval and resistance used for the leg press. Anaerobic capacity, as judged by a treadmill run to exhaustion at 20% grade improved by an average of 16.7%. Terminal blood lactate level increased by 14%. VO2max improved by an average of

only 4.1% (ml/kg/min). At the cellular level, there was a 3.3% increase in the proportion of fast twitch muscle fibers. This is not statistically significant, but till a relatively large change over 6-weeks! This study, however was conducted prior to the identification of fiber sub-types, so this was not evaluated, but probably occurred to a significant degree based on more recent research.

What is interesting is that although resting Creatine Phosphate concentration increased by 4.5% and resting ATP concentrations increased by a large amount (14.8%). Given more recent research on hyperplasia, we know that type 1C fibers are a type of low twitch fiber that takes on some of the characteristics of fast twitch fibers. These fibers have a larger amount of ATP concentration

Strength runs appear to cause physiological adaptations by increasing the stored concentrations of ATP indicating fiber sub-type transformation. They also help the muscles absorb the pounding of training and allow a runner to maintain the pace up hills. These are similar to the effects of weight training on muscle fiber type.

Table II-11 shows frequency recommendations of various 5-km running programs. As both types of training are anaerobic in nature, over-training is a primary concern. Most indicate that strength runs can be cut back if weight training is used simultaneously as they target the same physiological adaptations.

Source	Robinson 123*	Burke 124*	Newsholme 125*	Anderson 126*	McMillan 127*
Strength (Hills)	0-1 d/w	1 d/w	1 d/w (cross country run)	0-1 d/w	1 d/w (base only) vice tempo run

Table II-11: Frequency of Strength Runs

*Note: Recommends alternating hard and easy days.

4. OVER-TRAINING

a. Frequency

How much cardiovascular training causes over training. W. J. Kraemer et al. did a study training 6 days each week. The participants did 3 days of intervals and 3 days of fast continuous running (anaerobic threshold) on a treadmill. Based on the guidelines above, performing intervals three times a week and anaerobic threshold runs three times a week would seem to invite over training. The hormonal responses of this group in fact indicated that the training intensity and frequency might have elicited over-training.[128]

Another study by Lehmann et al studied recreational athletes on a 6 day/week program for 6 weeks. They performed lactate threshold and interval training on cycle ergometers training for 40-60-minutes each day ceasing at muscular exhaustion. The seventh day was a regeneration day of 30-40 minutes of low intensity training. The duration was increased in weeks 3 and 4 eliminating the regeneration day. Weeks 5 and 6 were used for regeneration (2h/week). Power input increased through three weeks, but decreased at week 6 despite two regeneration weeks. Obviously training seven days a week caused over training that not even two weeks of reduced training could repair.

A series of studies by M. L. Pollock et al showed that the amount of improvement in VO2max increases with the frequency of training. The slope of the improvement graphed over time became minimal after 5 days a week, but the incidence of injury increases significantly beyond 5 days per week.[129] The significance of this study is that there appears to be a point of diminishing returns.

b. Volume Vs Intensity

In a pair of companion, studies Lehmann et al studied the effects of over-training with an increase in training volume and an increase in training intensity. In the volume study, volume was increased 100% over 4 weeks. Almost all of the training consisted of long slow distance runs. All athletes failed to equal their personal records in a three month follow up. In the companion study, the total volume was increased by only 37%, but the proportion of intense training (tempo runs and intervals) was increased by 150%, following the concept of alternating hard and easy days. All athletes recorded personal bests during the three-month follow up.[130] The significance here is that increased volume has a more drastic and lasting affect of over training than an increase in intensity.

c. 3-Week Barrier

A series of tests on special forces soldiers and experienced athletes showed a decrease in performance after 2-3 h/d of training for 10-14 days, but super-compensation was exhibited after 1-2 weeks of recovery (tapering).[131] The conclusion was that athletes are at a risk of over-training after three weeks of intensive or prolonged endurance training (2-3 h/d). They further concluded that alternating hard and easy days and one complete day of rest each week limits the potential for over-reaching or over-training.[132] Interestingly, this study supported the anecdotal evidence that coaches have believed for several decades. This is important to the design of training programs.

d. Summary

The consensus is quite clear on four key points to avoid over training.. To avoid over training, at least one day a week must be complete rest. Hard days and easy days of cardiovascular training should be alternated and training crossing into the anaerobic spectrum (greater than 85-90% of reserve heart rate) should be limited to no more than once a week. After 3 weeks of hard training, additional recovery should be planned into the program.

5. CROSS TRAINING

Cross training is universally considered an excellent way to control the stress of over-training by shifting the stress from joints and soft tissue overuse in running. As cited above, several different studies have shown significant improvement in both VO2max and run times when mixing running with cycle ergometer training despite training 6 days a week. These mixed training programs produced significant results in run times although the participants only ran 3 days a week and cross-trained on a cycle ergometer for the 3 additional days.

In a 1993 study, Edward Eyestone et al, compared water running, cycle ergometer and running for maintenance of VO2max and 2-mile run times. Thirty-two trained subjects were tested for VO2max and 2-mile run time. They were then separated into ability groups and then randomly assigned to three different groups so that each group had a spread of ability groups. All three groups exercised at similar frequency, intensity and duration over a 6-week period. The study concluded that there was no significant difference in changes in VO2max or 2 mile run time between the three groups, thus

both water running and cycle ergometer training can maintain or even improve VO2max in injured runners. [133]

In another study subjects who exercised on a stair climbing machine 30-45 minutes, four days per week for nine weeks at 70-90% of MHR improved their 1.5-mile run time trial by an average of 1 minute. Even at an 8 minute pace, this equals an 8.5% increase in nine weeks! [134]

There are some differences in heart rate at VO2max for various forms of training. For instance, research has shown you must increase your heart rate range by 5-10 beats per minute on a cycle ergometer and decrease your heart rate range by 8-11 beats per minute in water running to equal the same percentage of VO2max you would achieve when running on a track. [135]

6. PERIODIZATION

Training in cycles provides guidelines for the times in the training program when regeneration should be complete and limits over-training. Exposing an athlete to increasing levels of stress has been called overload training. In order for the athlete to recover and adapt (super-compensation), periods of recovery must be built in and severe increases in amount of stress must be avoided. This state of lack of adaptation has been called overreaching. [136]

A training program must provide for overload training within tolerance and regeneration periods that optimize performance improvements, but avoid over-training. The cycling of these training and regeneration periods has been called periodization.[137] Fry, et al. cites studies indicate that several sessions in sequence can create a valley of fatigue necessary to induce training adaptation. It is unclear at present what the exact

number of sessions to create the optimum valley and what is the appropriate regeneration time.[138]

Periodization is nothing more than a training plan that changes your workout protocol at regular intervals and builds in regeneration cycles. Both aerobic and strength periodization plans generally use microcycles (7-10 days long) within mesocycles (generally 4-6 weeks), within macrocycles (6 months to a year). The running and power-lifting communities have used cycles geared to the competitive season. Generally, runners use a base phase, a strength phase, a stamina phase, a speed phase and a peaking phase.

7. SUMMARY

Summarizing the points from above and their application to program design:

a. Frequency: The consensus of coaches and experts in the field of running suggest that you must run 5-6 days a week. . Obviously, the lower end of this range is more appropriate if the subjects are also involved in high intensity resistance training.

b. Duration: Again, the experts are amazingly consistent in their recommendations. In preparation for a 5-K run, the base phase should build to an 8/10-mile weekly long run and 25-35 miles a week. As athletes transition to a stamina phase the mileage should drop as the intensity increases.

c. Intensity: There are three key workouts each week to sustain the energy systems most prevalent in the 5-K run; 1 tempo run or cruise interval session, one aerobic capacity interval session and one long run alternating each of these with easy days of recovery runs or rest. During the base phase, coaches often substitute fartlek

runs in lieu of intervals and during the peaking phase, add some anaerobic capacity as you decrease the amount of aerobic capacity intervals.

d. Over-training: The consensus is quite clear on four key points to avoid over training. To avoid over training, at least one day a week must be complete rest. Since we are combining, high intensity resistance training 2 days is a logical progression. Hard days and easy days of cardiovascular training should be alternated and training crossing into the anaerobic spectrum (greater than 85-90% of reserve heart rate) should be limited to no more than once a week. After 3 weeks of hard training, additional recovery should be planned into the program.

e. Cross-training: Previous studies that have combined bicycle ergometer intervals with running have had lesser problems with over-training, probably due to muscle recruitment order. Research consistently shows that cycle ergometer training can be substituted for running with no degradation in improvement of VO2max or run times. It therefore seems prudent to substitute this for at least one of the days of easy recovery runs to prevent soft tissue injuries particularly for middle aged runners.

f. Periodization: The most significant finding of all over-training studies is that you cannot increase intensity and distance simultaneously. Periodization is frequently cited as a solution to this problem. By increasing the mileage at no more than 10% a week during the base phase and gradually reducing the mileage as we increase the intensity in the stamina and peaking phases, you limit the opportunity for over-training. During a simultaneous high intensity endurance and strength program, the strength phase could logically be eliminated, as strength training is ongoing.

SECTION III: STRENGTH TRAINING

1. ACUTE VARIABLES

In 1983, using statistical analysis, Dr. W. J. Kraemer developed a set of variables that contribute the most significant change in results for a specific workout. These acute program variables describe all possible combinations within a single training session. They are exercise selection, order of exercise, number of sets, rest periods between sets, exercises & workouts and resistance used.[139]

Exercise variables play a significant role in the serum responses of human growth hormone. Kraemer et al found it readily apparent that even keeping total work constant; changing one program variable significantly alters the serum growth hormone response pattern.[140]

a. Choice of Exercise

The effectiveness of a program is strongly affected by the choice of exercise. Kraemer and Fleck, in their seminal work, "Designing Resistance Training Programs" categorize resistance exercises into two categories: structural, (Multi-joint), and single joint. Structural movements are those that require the coordinated action of several muscle groups, such as the squat, dead lift or power clean. Structural exercises are also called Multi-joint exercises or those exercises where movement occurs at multiple joints. Single joint exercises are those that isolate a specific muscle group. Examples are the sit-up, biceps curls, or leg extensions.[141]

Electromyography is a scientific method of measuring the level of excitement (electrical signal) in a working muscle group. Muscle contraction is initiated by electrical charges (ions) that move across muscle fibers. Scientists can measure this flow of ions

on the skin using a surface electromyogram (SEMG). [142,143] An SEMG is representative of the entire electrical activity in all of the motor units in a given muscle and the frequency of their firing rates during a given movement.[144]

The purpose of these studies was to find, using EMG recordings which exercises caused the greatest amount of stimulation within a muscle group. Exercises that produce the greatest amount of electrical activity during muscular contraction will produce the greatest amount of muscular efficiency. In their book " Serious Strength Training" Bompa and Cornacchia list exercises in order of IEMG activity for different muscle groups.

Coaches have know for years that whole-body exercises, or Multi-joint exercises are the best for building strength for sports such as football, wrestling or field events. The reason is that they stress the neuro-muscular links between muscles and require the generation of power. Because they involve the largest muscles of the body, they recruit the most muscle fibers. The studies cited above bore this out. The exercise that produced the greatest IEMG signal for the quadriceps (rectus femoris) muscle was the squat (90 degrees with a shoulder width stance). For the latissimus dorsi (back) muscle, it was bent-over rows and for the pectoralis major (chest), it was the decline and flat bench press. Dumbbells produced slightly greater recruitment than barbell.[145]

For the various muscle groups, Table II-12 lists the most effective exercises and the percentage of IEMG stimulation:[146]

There is some concern that Multi-joint exercises like the squat are dangerous. In a study at the Department of Health and Human Performance at Auburn University, Chandler, et al specifically studied the effect of the squat exercise on knee stability. In

this study, the authors measured one hundred male and female college students on nine tests of knee stability using a knee ligament arthrometer. Over an eight-week training period, full (below parallel) or half squats. In addition, the same measurements were collected on male powerlifters and male weightlifters. They found that not only did the 8 weeks of squat training (both full and half) not affect anterior and posterior knee stability, but that powerlifters and weightlifters with years of squatting had tighter knee joints (quadriceps active drawer measured at 90 degrees of knee flexion) than untrained individuals. The authors concluded that the squat had no affect on knee stability.[147]

Muscle	Best (% IEMG)	Second (%IEMG)
Pectoralis Major (Chest)	Decline Dumbbell and Barbell Press (93 & 89%)	Flat Bench Dumbbell and Barbell Press (87 & 85 %)
Pectoralis Minor	Incline Dumbbell Press (91%)	Incline Barbell Press (85%)
Medial Deltoids	Incline Dumbbell Side Laterals (66%)	Standing Dumbbell Side Laterals (63%)
Anterior Deltoids	Seated Front Dumbbell Press (79%)	Seated Front Dumbbell Raises (73%)
Biceps Brachii (Long Head)	Biceps Preacher Curl (Olympic Bar) (90%)	Incline Seated Dumbbell Curls (88%) and Standing Barbell Curl (86%)
Triceps Brachii (Outer Head)	Triceps Extension (Olympic Bar) (92%)	Triceps Pushdown (angled bar) (90%)
Latissimus Dorsi (Back)	Bent over Barbell Rows (93%)	1 Arm Dumbbell Rows (91%)
Quadriceps	Squats (90degree angle, shoulder-width stance) (88%)	Seated Leg Extensions (86%)
Biceps Femoris (Hamstring)	Standing Leg Curls (82%)	Lying Leg Curls (71%)

Table III: 12: Neural Activation for Resistance Exercises

The significance of these studies is that the choice of exercise does make a difference in the overall improvement in strength and muscle hypertrophy.

b. Order of Exercise.

For years, strength coaches have advised that the order of exercise be from largest muscle group to smallest group. The reasoning behind this concept was to avoid limiting the resistance that could be used in a large muscle group exercise (e.g. bench press for the chest) by first fatiguing the triceps muscles which assist in the bench press. To test this concept, Kraemer and Fleck compared the workout logs of 50 football players, some of whom placed squats at the beginning of the workout, and some of whom placed squats at the end of the workout. The results were that players who executed squats at the beginning of the workout were using significantly heavier resistance.[148]

Other authors refer to structural Multi-joint exercises as functional strength exercises. Unanimously, they call for these to precede single-joint exercises. The reason is that in doing functional strength exercises, you are also strengthening ligaments and thickening bones. Only substantial resistance places sufficient stress on the body to strengthen these ligaments and bones.[149] If you have placed these functional strength exercises at the end of the workout, as cited above, you will not lift enough weight to increase the stress on the muscular-skeletal system or recruit the type 2 fibers.

Health for Life, in their book Secrets of Advanced Bodybuilding has developed a principle called the interdependency of muscle groups. Their research has shown that one specific sequence of a given sequence of exercises is more effective than the same exercises performed in a random order. Their theory is that the body works as an integrated whole. It is impossible to activate one muscle without involving others.

During an exercise, the work is done by a "prime mover". These muscles are helped by "synergists". Other muscles keep you balanced by providing a foundation for stable movement. These muscles are called "stabilizers".[150]

In the example we used earlier, the bench press, the pectoralis muscles are prime movers, the anterior deltoids and the triceps are the stabilizers are the synergists and the latissimus, rhomboids, posterior deltoids and abdominal are the stabilizers.

From this principle, Health for Life defines a set of applications which can increase the effectiveness of a sequence of exercises by maximizing the sequence. Those applications are:[151]

1. Never work a muscle as a prime mover before that muscle is called on to work as a synergist.

2. Do compound sets using the same prime mover, but different synergists to further fatigue the prime mover.

3. Pre exhaust the prime mover first before doing an exercise where the synergist will tire first. The idea is for the exhaustion of the prime mover to be the limiting factor, not the exhaustion of the synergist.

4. Sequence exercises so that a muscle that acts as a synergist or stabilizer in one exercise acts as the prime mover in the next exercise.

c. Number of Sets.

There has been an ongoing debate for several decades over how many sets you need to achieve maximum hypertrophy and strength gains. It is apparent that there is some threshold of fatigue, tension[152]or strain that must be met to create the optimum stimulus for growth. [153] The stimulus must be sufficient to produce increased protein synthesis and thus hypertrophy in the muscle fibers.

Numerous studies have shown that in untrained individuals, almost any reasonable resistance-training program will initially induce growth. In fact, the American

College of Sports Medicine (ACSM) cites one set per exercise as its recommendation for quantity of exercise to promote health.[154] (The 1998 ACSM guidelines further state the multiple sets may promote greater gains if time is available).

In order to gain size, you must recruit more motor units. A single set can only recruit 80-85% of the motor units in a muscle. You must work your way through all of the motor units to get hypertrophy. After the initial period, gains using a one set format ultimately causes a plateau in performance gains. Studies bear this out. In those studies of more than 6 weeks, all have shown that multiple sets produce better gains than single sets, even in untrained individuals. [155,156,157,158,159]

Multiple sets have also been shown to promote greater endurance adaptations. In 1992, McGee, et al studied the effect of three different weight training programs on leg and hip endurance as measured by cycle endurance at 265 watts and parallel squat endurance. The authors found that one set to failure did not increase high intensity exercise endurance as effectively as the use of multiple sets. This supports research in cardiovascular exercise that equates higher loads (volume x intensity) with greater gains in endurance.[160]

That is not to say that one-set programs are not useful. They are frequently used by athletes who use multiple set programs in the off-season and a one-set program in-season to slow the loss of strength and muscular size while competing. The other clear instance is individuals who are time constrained. Business professionals who have competing priorities and have modified their goals from optimum strength or muscle size to general health or maintenance.

When you poll strength coaches on the optimum number of sets to elicit maximum strength and hypertrophy you find that they are consistent in recommending 2/3-6 sets for optimum strength and hypertrophy.

Author	**# of Sets**
Fleck & Kraemer 161	3-6
Stone et al. 162	3-5
Applewhite 163	2-6 (8 for leg press/squat)
Hatfield 164	2-5
Georgia State 165	4-6
Berger 166	3

Table III-13: Number of Sets

The total length of a workout, endurance or strength should not exceed 45-60 minutes total time. The hormonal response to exercise is for the body to begin secreting growth hormone shortly after the beginning of a workout. The body also begins secreting catabolic substances like cortisol, but the start is delayed relative to the production of growth hormone and testosterone. The difference in levels of growth hormone and cortisol is the net amount of protein synthesis that the body can optimally produce. Since the catabolic hormone curve is behind the anabolic curve, the difference begins to get smaller as you approach an hour. After an hour, the total amount of catabolic production begins to exceed anabolic production and growth potential is limited.

d. Rest between Exercises, Sets

Controlling the rest between sets or rest interval (RI) is probably the least used variable in workout design. Recent research has shown that the rest periods between sets and exercises control how much Phosphocreatine has been restored in the muscles and the level of lactate in the muscles. A series of studies by Kraemer, et al.[167,168,169,170,171] demonstrated the significant affect of rest periods on blood lactate, hormonal concentrations and metabolic responses to resistance training in both men and women.

The significance of the findings is that the amount of work and duration of force demands on the muscle determine the blood lactate levels, not the amount of resistance used. In this case 10 repetitions at 10 RM with one-minute rest periods caused significantly higher lactate concentrations in the blood than 5 repetitions at 5 RM with 3-minute rest intervals.[172]

The growth hormone response to a lifting session is directly related to the amount of lactic acid produced in the workout. Dr. Steve Fleck argues that the lactic acid response to a workout is directly correlated to the amount of work done in the total work session including rest periods.[173] In a study by Kraemer, et al. the researchers studied the growth hormone response to changing the load or rest period. In every combination, changing the rest period had a significantly greater affect on growth hormone response, both during exercise and up to 2 hours afterwards.[174]

High blood lactate levels must be slowly introduced into the workout program so the body has time to build up the buffering mechanisms. In some sports like wrestling,

where the athlete must perform under conditions of high lactate concentrations, this form of training should ultimately reach a very high level.

Interestingly, the same mechanisms that buffer lactate during these resistance programs are the ones used when running at anaerobic threshold pace. This concept has obvious application to increasing middle distance running performance.

An inadequate rest interval obviously puts a lot of stress on the lactic acid system for energy because less phosphocreatine has been restored to the muscles. Reliance on lactic acid as a fuel means a greater accumulation of it in the blood and muscles. This, in turn reduces the ability of the body to produce force.

In their book, "Serious Strength Training", Bompa and Cornacchia define several physiological cues for rest intervals:[175]

1. A 30-second RI restores approximately 50% of the depleted ATP/CP.
2. A RI of 3-5 minutes or longer allows almost entire restoration of ATP/CP
3. After working to exhaustion, a 4-minute RI is not sufficient to eliminate lactic acid or replenish glycogen stores.

In his address to the international summit of personal trainers, Mitchell S. Simon, MS, RTS, CPT, noted that the half-life of PCr is 20-28 seconds. In other words, after about 30 seconds, the body has restored 50%. After the next 30 seconds 75% has been restored. The body has almost completely restored its PCr stores in 8 minutes. That is the reason you watch a power lifter in the gym do a very heavy set and sit on the end of the bench for 8-10 minutes before the next set.

In addition, the nervous system must recover. When the brain sends a to a muscle signal to contract it transmits a nerve impulse. The stronger the nerve impulse, the stronger the contraction. When the muscle is tired, chemical disturbances are

signaled back to the central nervous system and the brain sends weaker nerve impulses to protect the body. Following a set, a 2-3 minute RI usually returns the nerve impulses to full strength.[176]

Bompa and Cornacchia offer the following guidelines on rest intervals:[177]

Load (% 1RM)	**Rest Interval (minutes)**	**Applicability**
>105% (eccentric)	4-5/7	Maximum Strength
80-100%	3-5/7	Maximum Strength
60-80%	< 2	Muscle Hypertrophy
50-80%	4-5	Power
30-50%	1-2	Muscle Endurance (definition)

Table III-14: Rest Intervals between Sets

These guidelines are almost identical to those offered by other strength coaches and scientific studies. For muscle hypertrophy, there is a great deal of evidence that lower rest intervals produce greater hypertrophy. In a series of studies by Kraemer, et al. a medium length rest period (1-3 minutes) resulted in a blood profile (increased growth hormone and testosterone) that leads to muscle growth.[178,179,180,181] A medium length rest period allows enough rest to replenish phosphocreatine and allows the use of a heavy enough weight to increase strength.

Heavier resistance requires longer rest periods because the body has had to recruit the type 2 fibers and further exhausted the muscle. Long rest period (longer than 5 minutes) allow for almost complete recovery of phosphocreatine and allow near-

maximal resistance to be used.[182] Thus when the goal is to increase strength and power heavier resistance and longer rest periods are appropriate.

Health for Life describes the difference as tension level and fatigue level. The greater the weight lifted, the greater the tension level and the greater the strength gains. The shorter the rest between sets, the greater the cumulative fatigue level. The greater the fatigue level, the greater the potential for hypertrophy. They hypothesis a fatigue/tension threshold which you must cross to cause growth. The fatigue/tension threshold can be crossed by a combination of greater resistance and/or shorter rest intervals.[183]

e. Resistance Used (Number of Repetitions)

The resistance used is probably the most important variable used in the design of a training program. The scientific community has coined the term “repetition maximum” or the exact resistance that allows for the execution of a specific number of repetitions, but not one more repetition. The maximum weight that a lifter can lift one time in a given exercise would be a 1RM. The maximum weight that he could lift 10 time would be 10RM.

In what is probably the most cited study on number of repetitions, Richard Berger studied 199 college students to determine the optimum number of repetitions for strength gain. Nine groups were tested for bench press strength before and after 12 weeks of strength training. The author used resistance which allowed 2RM, 4RM, 6RM, 10RM and 12 RM for one set to failure. By using one set in all groups, the variable of training volume was controlled. Resistance was increased when any subject could do one more than the specified number of repetitions. The author found that training with

less than 2 repetitions and more than 10 repetitions will not improve strength as rapidly as training with 4,6,or 8 repetitions. They concluded that the optimum for strength gains was 3-9 number of repetitions.[184] Research supports a scale of repetition maximum ranges that correlate to training effects that they produce. In general, six or fewer repetitions target strength gains. The strength gains above 25 repetitions are insignificantly small or non-existent. Any strength gains produced with these higher levels of repetitions are probably due to neuro-muscular pattern efficiency.

A resistance of at least 60% of 1-RM is considered the minimum for optimum development of strength. Many strength coaches and popular strength books define resistance lower than that as a "warm-up" set and do not count it in program design.

Fleck and Kraemer, in their seminal work "Designing Resistance Training Programs" quantify the RM continuum. These recommendations are very consistent with all other findings on the subject.

Objective of Training / Number of Reps	**Fleck & Kraemer** 185	**Hatfield** 186	**Georgia State U.** 187 188	**Bompa & Cornacchia** 189
Strength	< 6	3-8	1-4	1-7
Hypertrophy	6-12	4-12	6-12	6-12
Local Muscular Endurance	12-20	25-40		30-150

Table III-15: Number of Repetitions

These findings are supported by a number of studies in which low repetition training (3-5 RM) produces significantly greater strength, intermediate repetition training (6-12 RM) produces the greatest hypertrophy and high repetition training (22-26 RM)

produces significantly greater local muscular endurance.[190,191,192] Six to eight repetitions appears to be the optimum compromise between hypertrophy and strength.

At some point in a workout, a lifter must go to temporary concentric failure. You have not reached overload and will not cause the muscle to grow until you do so. Beyond temporary concentric failure, however, a lifter may actually defeat the body's ability to hypertrophy. Once you go beyond failure by using forced repetitions or negative repetitions, the strength of the muscle fiber is already gone. The additional effort is made up by the nervous system. During recovery, the body will preferentially recover the nervous system over the muscles. This makes sense, as the nervous system is the "conductor" of recovery. To allow hypertrophy, the body must send all of its recovery into protein synthesis not recovery of the central nervous system. It may be more appropriate to recruit additional motor units in the next set as opposed to extending sets with heavy forced repetitions.

f. Frequency

To a great degree, the frequency of workouts depends on the experience and recoverability of the lifter. Early studies and the current guidelines from the American College of Sports Medicine all indicated that 3 days of lifting, with a day of rest between each workout allowed adequate recovery for novice lifters and produced strength gains.

What the studies are really saying is that a muscle can be trained every other day. Muscles gain strength and size during the rest period between exercise periods. This does not mean that another muscle cannot be worked while one is resting.

Exercising every muscle in the body on the same day can lead to marathon workouts. Focusing a workout on one or two specific muscle groups and alternating the

muscles to be worked each day can and has led to development of programs involving 5-7 days a week without over training a given muscle group.

In one study, a significantly greater improvement in strength was found on a 5d/w schedule vice 2 and 3 days per week.[193] Other studies also indicated that 4(consecutive) or 5 times a week will produce greater strength gains,[194,195] but in many cases, the workout designs in these studies were flawed.

In many cases, the participants executed the same exercises every day of the week vice splitting the muscle groups up over several days. No one designing resistance-training programs in the sports world would ever suggest this type of scheme. In addition, the number of exercises performed was very small. This certainly accomplishes the scientific requirement to isolate variables, but ignores the realities of training the entire body for athletic performance.

In a much larger study using a proven resistance-training program, Hoffman and Kraemer et al, studied the effects of self selection of a training frequency on sixty-one members of a division 1AA football team in the off-season.

All participants used a periodized approach including structural exercises and assistance exercises. The set/rep schemes for the structural exercises progressed from 4 x 8 in the first 4 weeks, 5 x 6 in the second four weeks and (10,8,6,4,2,10,10,10) in the last two weeks. Assistance exercises were held constant at 3 x 10.

In addition to the weight training, the players participated in a two-day a week conditioning program consisting of flexibility, agility, endurance, speed training and plyometrics. The options are listed in the table below:[196]

Frequency	Frequency / Muscle Group	Sets / Week	Days	Muscle Groups
3d/week	3/week	150-162	M,W,F	Entire Body
4d/week	3/week	118-126	M,TH T,F	Chest, Shoulders, Triceps, Neck Legs, Back, Biceps, Forearm
5d/week	3/week	148-156	M,W,F T,TH	Chest, Triceps, Legs, Neck, Back, Shoulders, Biceps, Forearms
6d/week	2/week	154-162	M,TH T,F W,SA	Chest, Triceps Legs, Shoulders, Neck Back, Biceps, Forearms

Table III-16: Frequency

The results of the study showed a distinct lack of improvement in any strength measure for the 3d/week group. All groups significantly decreased 2-mile run times and body fat. The 6 d/week group had the highest average improvements in bench press (5.8 kg) and squat (12.5 kg) but the differences between players made the bench press measure for the 6/d week group statistically insignificant. Part of the reason may have been that there were an extraordinarily high number of exercises for chest and shoulders (7 and 8 respectively). This could have caused over-training. The 5d/week format was concluded to elicit the best performance in strength.

A review of the suggested frequencies from popular and scientific strength experts indicates remarkable consistency:

Author / Objective	Hypertrophy	Strength
Fleck and Kraemer[197]	6d/week Body Split:3	4d/week Body Split:2
Georgia State University[198,199]	5-6 d/week Body Split:3	2-4 d/week Body Split: 2
Tesch in "Strength & Power in Sport[200]	6d/week (4 0n/ 1 off w/ 4 way split) or (6 on/ 1 off w/ 3 way split)	Soviet Model: 5d/week Body Split 1-2

Table III-17: Frequency: Hypertrophy Vs Strength/Power

2. CENTRAL NERVOUS SYSTEM

In 1988, Hakkinen, et al. did a 2 year study of elite male weight lifters. Over two years of well designed training, they gained a 37.9-kg (2.8%) in maximum weight-lifting total. There was a slight increase in muscle fiber size (.7 cm) but the magnitude of size increase would not account for this relatively large (for trained athletes) jump in strength. What made the difference? The averaged IEMG activity of the examined muscles went up by a large, but not statistically significant 4.2%.201

Dr. Steve Fleck interpreted this data to mean; that once you approach or hit your genetic ceiling on physiological strength, the only remaining variable that you can improve is neural activation or IEMG activity.202 As you approach your genetic potential and the bulk of the gains in strength are from increasing neural pattern efficiency or motor unit recruitment, the gains become smaller and smaller.

This interpretation is supported by numerous studies that found large initial increases (10-20%) in maximal strength in previously untrained subjects. As the upper

limit of strength is approached, however, increases in muscle size and consequently strength are very difficult to achieve.202 When working with United States Olympic Weight Lifters, Dr. Fleck noted that a gain of 2 Lb. of lean body weight in one year was a significant gain.203

At the higher levels of neuro-muscular efficiency, the antagonist muscles actually decrease in IEMG activity when a muscle is firing, thus increasing the neural signals to the motor neurons in the firing muscle and lessening the wasted force vectors from antagonist muscles, often found in untrained subjects.

In a study by Moritani and DeVries a 30%, increase in performance (strength) was studied to determine the neural factors and hypertrophic factors of the gain. The study concluded that 9% of the gain was caused by hypertrophy of the muscle fibers, and 12% of the gain was caused by increased IEMG activity in the working muscle.204 (Increased IEMG activity in a working muscle means that more motor units have been recruited; that motor units are firing at higher rates or some combination of the two adaptations is occurring). They found the remaining 9% to be the relaxing or lessening of IEMG in the antagonist muscles.

In a recent study, researchers found a 23% gain in bench press in 48 hours from one training session to another. Since it takes 7-10 days for protein synthesis to add muscle, this is clearly not hypertrophy, but neural gains.[205]

3. PERIODIZATION

a. Weight Training Systems

Prior to the recent studies on periodization, in both the weight training and scientific communities, there has been continuous debate over the relative efficiency of one or another systems of weight training. In a landmark study Leighton et al studied over 300 college students, using 10 different weight- training systems over eight weeks. This study is significant in that the number of participants is unusually large for an anaerobic exercise format. For safety, most studies involving anaerobic exercise are kept small. The ten different systems are briefly described below.[206]

1. Power: Increase loads and decrease the number of repetitions on each set.
2. Superset: Using 2 exercises for the same muscle group or antagonistic groups with little or no rest between exercises.
3. Cheating: Bringing in other muscle groups to assist in the exercise in order to handle heavier poundage i. e. rocking with the lower back to help with a barbell curl.
4. Bulk: Multiple sets using the same repetitions and load for each set.
5. Tri-set: 3 exercises for the same body segment- can include different muscles- with little or no rest between exercises.
6. Double-progressive: Increasing the resistance by first reaching a specified number of repetitions and then increasing the load and decreasing the repetitions to the original number.
7. Heavy-Light: Using maximal poundage for one workout period each week and 2/3 maximal poundage during the other periods that week.
8. DeLorme: Three sets with 10 repetitions each. The first with ½ maximal load, the second with 2/3 maximal load and the last with maximal load (10RM).
9. Oxford: The same poundage and number of sets as DeLorme, but in reverse order.

10. Isometric: A single maximal contraction held for 6 seconds.

The cheating and tri-set routines elicited the greatest improvement in arm flexor and arm extensor strength, although the heavy-light and Oxford systems were nearly equal. In leg strength, the bulk system was clearly superior. Interestingly, the isometric system caused actual but insignificant losses in strength.[207]

b. Periodization Works.

The sports science community began comparing periodized resistance protocols to conventional protocols in the early 1980's. In 1983, Stowers et al. compared the short-term (7 weeks) affects of three different strength-power training methods on trained weight lifters. Each group trained 3 days a week. They compared 1 set of 10-12 repetitions, 3 sets of 10 repetitions and a periodized approach. After warm up sets, the 1 set group executed 1 set of each exercise using 10-12 repetitions to exhaustion. After warm up sets, the 3 set group did 3 sets of 10-12 repetitions to exhaustion, lowering the weight after each set as appropriate to stay within the repetition scale. The periodized group did 5 sets of 10 for 2 weeks, 3 sets of 5 for 3 weeks and 3 sets of 3 for the last two weeks. The results are listed in table:

Group/measure	**Bench Press**	**Squat**	**Vertical Jump**
1 set	6.6 Kg	15.2 kg	.2 cm
3 sets	8.3kg	20.3 kg	.7 cm
Periodized	7.4 kg	27.o kg	5.7 cm

Table III-18: Periodization: Stowers et al

Of interest is that the 3 set group showed relatively equal improvements to the periodized group in all three areas, but reached a plateau in the final two weeks. The periodized group was still improving when the test ended. In addition, of significance is

that the improvement in vertical jump of the periodized group was over 800% of the 3 set group and 2800% of the one set group. This indicates that motor unit recruitment or neural performance was significantly affected by the periodized protocol.

In a more recent study by Darryn S. Willoughby from the Department of Health and Kinesiology at Texas A&M University studied 92 participants, again a large population for a study on anaerobic exercise. This study is also significant because it used participants with previous weight training. It has been clearly shown that untrained subjects will gain significant strength and hypertrophy on almost any program. All participants for this study had to have at least 3 years of previous weight training experience and have abstained for 6 months prior to the study.[208] To participate lifters had to be able to bench press 120% of body weight and squat 150% of their body weight. This implies a great deal of previously developed strength. The study is also significant in that is lasted 16 weeks, much longer than previous studies, and it partially equated the volume of training among the different groups.

All groups trained 3 times each week on Monday, Wednesday and Friday and were tested on free weight bench press with an Olympic bar and parallel back squat.

Group 1 trained with 5 sets of 10-RM using 78.9% of 1-RM. Group 2 trained with 6 sets of 8-RM using a resistance of 83.3% of 1-RM. The resistance for both groups was increased if appropriate after each 4-week test. Group 3 used a periodized approach with 4 weeks at 5 sets of 10-RM with 78.9% of 1-RM; 4 weeks at 4 sets of 8-RM with 83.3% of 1-RM; 4 weeks at 3 sets of 6-RM using 87.6% of 1-RM; and 4 weeks of 3 sets of 4-RM using 92.4% of 1-RM.

This protocol was an obvious progression of decrease in volume and increase in intensity. The volume of training was nearly equal until after week 8 when group 3 decreased below the other 2 groups. Group 4 was a control group that met all of the prior experience prerequisites, but abstained from weight training during the 16 weeks.[209]

A 4 x 5 MANOVA with repeated measures on test showed pre-test bench and squat values were statistically equal when the study began.[210] At the end of the weeks 8,12 and 16, group 3 showed significantly greater strength gains over the other three groups. Groups 1 and 2 showed lesser gains in strength that were statistically equal at weeks 8,12 and 16.[211]The results are listed in table x:

Group/Measure	**Bench Press**	**Squat**
3 sets of 10	8%	13%
3 sets of 6-8	17%	26%
Periodized	28%	48%

Table III-19: Periodization: Willoughby

The implications are clear that some variation in training improves strength gains. In comparative studies and reviews the results consistently found that in short term training, periodization produces significantly greater strength gains than traditional methods.[212,213,214,215,216]

c. Periodization Cycles.

The terms used to define training phase length in a periodized program have become relatively standard in the strength and scientific communities:[217]

(1) Macrocycle: Although it is normally used to describe one entire year, it can describe a period of as little as 6 months or as long as 4 years in the case of Olympic

athletes. It is generally thought of as beginning and ending after the last competition of a season.

(2) Mesocycle: Originally used to define the major training cycles of an entire year of training. Recent evidence clearly shows that to elicit continuing gains, changes must be made every 4-6 weeks. This term has thus been altered from a period of 2-3 months to one of 4-6 weeks.

(3) Microcycle: Most coaches and scientists use microcycle to refer to a period of seven days to correspond to the week. There is some ongoing evidence that a cycle of 10 or 14 days may be ideal to prevent over training, but in general a microcycle today still defines a 7-day period.

Lifters and lifting coaches from strength and power sports use five phases or mesocycles: Hypertrophy phase; Strength phase; Power phase; Peaking phase and Active rest phase.

4. OVER-TRAINING

a. What is Over-Training

Progressive overload is the foundation of successful adaptation to training. Overload is the stress that causes fatigue (temporary decrease in exercise ability), and adaptation is the improved performance (following recovery from that fatigue).[218]

If you were to draw a graph of responses to training in relation to genetic potential the over-reaching phenomenon would stand out clearly. A planned suppression in performance caused by an increase in training is followed by a rebound closer to

optimum potential. If the suppression continues too long, the athlete is in a state of over-training. True acute over-training requires months of recovery.

Callister et al. increased the volume of resistance training, running and judo practice in the U. S. National Judo Team over six weeks. The expected increase of resting heart rate or resting blood pressure did not occur. What they did observe was significantly decreased times in 300-m sprints and decreased isokinetic force production.[219]

The first controlled model to create and study over-training in a lab was done by Fry et al. They specifically identified suppressed testosterone and elevated cortisol endocrine profiles as markers of anaerobic over-training.

b. Application of Acute Variables in Over-Training

Manipulation of the acute variables, described by Fleck and Kraemer are the means of progression in strength training. Mistakes in the application of these variables lead to over-training. The use of periodization is an attempt to plan the progression for optimum adaptive response while preventing over-training.

(1) Choice of Exercise

You can classify weight training equipment as fixed form or free form. Free form involves equipment like free weights that allow movement through multiple planes of motion and require balance. Fixed form fixes the position and range of motion, normally isolating the muscle at a specific joint. A lack of variation in the pattern of motor unit recruitment means lack of development in the target muscle. In an isolation exercise, you deprive the muscle of the requirement for balance thus not training the synergist muscles. In addition, not providing for balance in the growth of antagonist muscle

groups around a joint (like the quadriceps and hamstring muscles) can create dangerous muscle imbalances. The choice of exercise is critical to the balanced development of muscles in order to prevent over-training through injury.

(2) Order of Exercise.

A plateau in the adaptive training response is possible if you exercise muscles in a fatigued state. The use of pre-exhaustion techniques, using isolation exercises prior to Multi-joint exercises clearly causes this fatigue. A maximum load must be used if you want to achieve maximum gains in strength. This implies placing structural exercises at the beginning of a workout.

(3) Number of Sets

Work is generally defined as sets x repetitions x load. If total work is increased too quickly, the muscles do not recover, causing over-training. The clear implication is a planned progression of workload over time to achieve optimum adaptation.

(4) Amount of Rest between Sets and Exercises

This variable has dramatic effects on the acid-base status of muscle and energy substrate utilization and depletion patterns.[220] Rest periods of less than 1-minute have been shown to create blood lactate concentrations of greater than 10 mmol/L in untrained individuals and as high as 20 mmol/L in elite lifters. Since direct links to muscle fatigue have recently been attributed to hydrogen ions as well as the lactate itself, about 8-weeks is required to develop the body's lactate buffering systems. The implication for training is building lactate levels too high, too early in training will cause over-training. A planned progression in the interactive variables (e. g. number of sets;

number of repetitions; resistance used and rest between sets) is critical to allow for progressive adaptation.

(5) Rest between Workouts

Even one day between workouts has been shown to significantly reduce the markers of over-training. In two studies by Fry, et al. recreationally trained athletes performed 8 sets of machine squats at 95% of 1-RM, six days a week. No reduction of 1-RM was observed however several other signs of over-training were observed, specifically sprint times and agility to the non-dominant side. The conclusion was that the body protects high force production of 1-RM and even one day of recovery a week allowed tolerance of this protocol.[221]

In the follow up study, the day of rest was eliminated resulting in significant decrease in 1-RM strength in 73% of the participants. Interestingly, some participants were still making progress and were not yet in an over-trained state. Clearly, the adaptation to stress is an individual response, but some clear guidelines have emerged for program design.[222]

5. SUMMARY

Summarizing the points from above and their application to program design:

a. Choice of Exercise: Electromyography clearly indicates that some exercises are better than others for recruiting motor units within a muscle. Structural or Multi-joint exercises are generally more effective than isolation exercises. In the development of a resistance training program too many exercises can lead to over-training, thus in attempting to recruit as many motor units as possible, the selection of exercises must include those that are more effective (see table III-1).

b. Order of Exercise: The preponderance of evidence indicates that structural or Multi-joint exercises should precede isolation exercises in a program. This allows the use of maximal resistance thus greater gains in strength. In general, you should sequence exercises so that a muscle does not act as a synergist before it is called on to become a prime mover so the point of failure is the prime mover and not a synergist or assistance muscle.

c. Number of Sets: Multiple sets are better than a single set and the optimum number of sets for hypertrophy and strength improvement is somewhere between three and six.

d. Rest between Sets. A muscles needs between 3 and 5 minutes to almost entirely replenish its phosphocreatine stores, however after 30 seconds, almost half of the CP is restored. The nervous system needs 2-3 minutes to return nerve impulses to full strength. The fatigue-tension principle indicates that a combination of load and rest period creates a fatigue/tension threshold that must be crossed in multiple sets to create the conditions for optimum growth. Medium-length rest intervals (1-3 minutes) creates a blood profile (increased growth hormone and testosterone) that causes hypertrophy. Heavier resistance, required for optimum increase in strength require longer rest periods (3-5 minutes) to fully replenish the CP stores in a muscle and revive the nervous system.

e. Resistance: A load of 60% of 1-RM is the minimum required for developing strength. Less than this primarily enhances muscle endurance by increasing lactic acid buffering capacity in the muscle. The strength gains beyond 20-25 repetitions are insignificant. Six or less repetitions appear to be optimum for increases in strength. Six

to twelve repetitions affect muscle hypertrophy and repetitions greater than 12 tend to enhance muscular endurance more than strength.

f. Frequency: A muscle needs 24-48 hours to recover from a resistance-training workout. The minimum number of days each week to train for optimum strength gains appears to be about three. Several major studies and the preponderance of popular strength and body-building coaches indicate that 5-6 days a week, splitting the body into groups of muscles is the most effective approach to hypertrophy and strength.

g. Periodization: It works. A planned variation in the acute variables over time produces significantly greater muscle gains that any combination of variables. In strength sports, the cycles should be 4-6 weeks long, progressing from hypertrophy to strength to power to peaking to active rest. If power lifting is not one of the program goals, the strength phase can be extended slightly.

h. Over-Training: The body must have at least one day of recovery each week from resistance training. The planned periodization of acute variables provides a clear advantage in avoiding over-training in strength athletes.

SECTION IV: COMBINED STRENGTH AND ENDURANCE TRAINING

Training is specific. More particularly, the cellular changes in the muscle are specific to the type of exercise. Are strength and endurance exercise compatible? Exercise compatibility studies have focused on endurance and strength compatibility in the last 2 decades.

1. INITIAL STUDIES

The question exercise compatibility first surfaced in the exercise science community in 1980, when Hickson compared three groups over 10 weeks of training. Group 1 did both high intensity resistance and high intensity aerobic training. Group 2 did only high intensity resistance training. Group three did only high intensity aerobic training. His conclusion was that although strength training did not compromise improvement in aerobic capacity, endurance training compromised simultaneous strength training.

The design of the study has some potential flaws as a model for combined training. The strength component, used by both the strength group and the combined group focused solely on leg strength. Three days a week they performed 5 sets of parallel squats at 5-RM, and 3 sets of knee extensions and knee flexion at 5-RM. On alternate days they 3 sets of leg presses at 5-RM and 3 sets of calve raises at 20-RM. Rest intervals were 3 minutes for all sets.

In other words, they worked legs five days a week. What is interesting is for the first 7 weeks, the rate of improvement for the strength and combined groups was identical, with both groups improving by an average of 26-kg in the parallel squat to that point. The strength only group continued to improve to an end-point of 42-kg by the

tenth week. The combined group's improvement leveled out during week 8 and actually declined during weeks 9 and 19 to an overall average of 22-kg above start.[223]

The endurance-training program combined 6 days of intense training. Three days a week the [participants performed bicycle ergometer intervals (six 5-min intervals at VO2max separated by 2-min rest intervals). On the alternate 3 days, they ran continuously as fast as possible building from 30 minutes a day during the 1st week to 40 minutes a day by week 3. There was no difference in the improvement of VO2max in the strength and combined groups, with both improving 17% over 10 weeks.[224]

Since the time of this study, significant evidence has shown that alternating hard and easy days will help to prevent over-training. In this study, they trained hard every day. The gains were beginning to level off by the tenth week for both the endurance group and the combined group. The significance of this study is that endurance training was not compromised by simultaneous strength training, despite the extremely high volume of intensity in both protocols.

2. POWER, NOT STRENGTH MAY BE AFFECTED

In 1985, Dudley and Djamil studied a significantly lower volume of combined training for seven weeks. Strength training consisted of 2 sets of knee extensions 3 days a week for 30 seconds (26-28 contractions) separated by 5 minutes. Aerobic training involved 5 sets of 5 minutes achieving VO2max in the 4th or 5th minute, separated by 5-minute rest intervals. The combined group alternated endurance training days with strength training days. As in the Hickson study, the improvement of aerobic capacity was not affected by the combined training. Combined training did not

affect the high force, slow velocity 1-RM strength. The high velocity component of strength (angle specific peak torque at fast velocity) was compromised. This was the first study to suggest that combined strength and endurance training might affect power, vice strength.[225]

3. A MORE REALISTIC PROTOCOL

In 1987, Hunter, Demment and Miller examined what coaches would consider a much more realistic training program of combined exercise. Participants executed 8 workouts a week for 12 weeks. The strength portion consisted of 6 exercises: bench press, seated press, lat. pull down, two-hand curl, squat and leg curl. They executed 3 sets of 7-10 repetitions, adding weight when they were able to do 3 sets of 10 repetitions. The endurance portion consisted of continuous runs at 75% of heart rate reserve increasing from 20 minutes the first week to 40 minutes in the eight-week and beyond. The subjects trained 6 days each week, with two days including both strength and endurance workouts.[226]

In addition to the 3 standard groups, they included a group of trained endurance athletes who executed combined training. As in previous studies the improvement of VO2max for the untrained endurance and combined groups were identical (33%). The trained endurance athletes had, as would be expected a lesser increase in VO2max.

Although the combined group improved similarly to the strength group in the parallel squat, the strength group improved vertical jump by almost twice as much. Interestingly, the endurance athletes executing combined training had the greatest overall improvement in bench press, squat and equaled the strength group in vertical

jump. Hunter et al. concluded that power, but not strength may be compromised in <u>untrained</u> individuals training simultaneously for strength and endurance. If the <u>endurance component is maintained at previously established levels (32-K/week in this case) power was not compromised</u>.[227]

In a more recent 10-week study, McCarthy et al. used a much more typical training routine with sedentary adult males. The strength group performed 3 sets to failure of 8 exercises (bench press, squat, barbell curl, knee extension, leg curl, wide grip pull-downs, overhead press and heel raises). The range of repetitions was 5-7 with the goal being a 6-RM on each set. The strength protocol was executed 3 days a week. The endurance protocol involved 3 days a week of continuous cycle ergometry, building from 30 to 50 minutes at 70% of reserve heart rate. The intensity was recalculated every two weeks. The combined group performed the same protocols on the same day. The order of training was rotated and the training sessions were separated by 10-20 minutes.[228]

The results indicated that the magnitude of increase in both strength and VO2max were the same for the combined protocol as the strength and aerobic protocols performed separately.[229] The significance of this study was that the subjects in the combined group had 4 days a week of recovery, vice one day in previous studies. Obviously, for even untrained subjects, combining training effects is possible.

These results were supported in a study by Volpe et al. Previously sedentary college females were placed on a 9 week periodized weight training program. The combined group ran prior to their weight training. They started at 20 minutes of run-walk and progressed to 25 minutes of running at 75% of reserve heart rate. The

combined group performed significantly better than the strength only group in the 12-minute run after training, thus there was a significant improvement in aerobic capacity. There were no statistical differences in the strength improvements between the strength and combined groups.[230]

4. THE CELLULAR LEVEL

There have been several studies attempting to explain the cellular affects of simultaneous strength and endurance training. The muscle fiber is faced with a dilemma. As explained in the physiology section, the muscle must try to increase mitochondria, oxidative enzymes, triglyceride stores and capillary density to improve aerobic function or to increase the enzymes that assist in force production. In other words, do muscle fibers move towards type 1 characteristics or type 2 characteristics?

Kraemer et al. studied these cellular changes over a 3-month period in 1995. The training protocol involved 4 days a week. The strength component was 2 days of 5 sets of 5-RM and 2 days of 3 sets of 10-RM. The running involved 2 days of intervals at 95-100% of VO2max and 2 days of continuous running for 40 minutes at 80-85% of VO2max. The workouts for the combined groups were planned such that the high lactic acid workouts (10-Rm and Intervals) were not executed on the same day. This study included a 4th exercise group that did only upper body exercises and running.[231]

The results supported previous studies in that VO2max increased significantly for both combined groups and the endurance only group, although the endurance only group improved slightly more than either combined group. The improvement in the combined groups was almost identical.

Muscle fiber transformation was unique to the groups. The combined group had a significant increase in both size and percentage of type 2a fibers. The upper body combined group saw a significant increase in percentage of 2c and 2a muscle fibers along with a significant decrease in percentage of type 2b fibers. No increase in fiber size was noted. The strength only group realized significant increases in percentage of type 2a fibers and significant decreases in percentage of type 2b fibers. In addition, the strength only group had significant increase in fiber area in type 1, 2c and 2a fibers. The endurance only group had a significant increase in percentage of type 2c and 2a fibers and a significant decrease in the percentage of type 2b fibers. The endurance only group also saw a significant decrease in the size of type 1 and 2c fibers.

These findings support Dudley and Djamil in that power was compromised in the combined groups. The 1-RM strength of the combined group appears to be similar to that of the strength only group. The upper body only combined group had similar improvements to the strength only group in upper body strength, but not lower body strength.

A study by Craig et al. in 1991 also supports these findings. Craig also found that a program of running and lifting could produce the same gains in VO2max and upper body strength. Craig found, however that combined training did not elicit similar lower body strength. In Craig's study, the lifting program immediately followed the running. They hypothesize that this was the cause of the lack of lower body strength improvement.

The protocol is, however, at odds with the findings on frequency of both resistance and aerobic protocols developed in the last two sections. In the endurance protocol of

this study, there were four hard runs in a week and the strength protocol worked the same muscle groups 4 days a week. The unanswered question is the effect of combining popular protocols. For instance one involving a 5-K running program with only one day of intervals and one day of lactate threshold runs each week and a strength program which splits the body up and works each muscle group only 1 ½ – 2 times a week.

SECTION V: CONCLUSION

1. SUMMARY

To summarize the results from the previous 4 sections, a combined training program would include each of the points in the individual summaries of each section. The tables below represent those summaries in the form of a recommended training program. This is a program designed specifically for increasing cardiovascular performance in middle distance running and 1-RM strength. A program tailored for a specific sport would obviously be different. The program outlined above uses 11 workouts a week with 5 days a week being two workouts a day and one day completely off for regeneration. The next chapter will deal with time constrained programs.

The strength program will split the muscle groups into 4 days, executing 6 workouts each week. In this way, each muscle group is worked 3 times in two weeks with Sunday completely off.

2. RECOMMENDATION

Table V-20: **Periodization**

	Mesocycle 1: (4-8 weeks)	Mesocycle 2: (4 weeks)	Mesocycle 3: (4 weeks)
Aerobic	Base Phase	Stamina Phase	Peaking Phase
Strength	Hypertrophy Phase	Strength Phase	Peaking Phase

Table V-21: **Schedule**

Week / Day	Workout	Week 1	Week 2	Week 3	Week 4
Monday	1	Run: Tempo	Run: Tempo	Run: Tempo	Run: Tempo
	2	Chest	Legs	Chest	Legs
Tuesday	1	Bike	Bike	Bike	Bike
	2	Shoulders, Triceps	Back, Biceps	Shoulders, Triceps	Back, Biceps
Wednesday	1	Intervals	Intervals	Intervals	Intervals
	2	Legs	Chest	Legs	Chest
Thursday	1	OFF	OFF	OFF	OFF
	2	Back, Biceps	Shoulders, Triceps	Back, Biceps	Shoulders, Triceps
Friday	1	Run: Easy	Run: Easy	Run: Easy	Run: Easy
	2	Chest	Back, Biceps	Chest	Back, Biceps
Saturday	1	Run: Long	Run: Long	Run: Long	OFF
	2	Shoulders, Triceps	Legs	Shoulders, Triceps	OFF
Sunday		OFF			

Table V-22: **Acute Variables: Strength**

Phase	Exercises/ muscle group	Sets (MJ) per exercise	Reps (MJ)	Rest (MJ)	Sets (SJ) per exercise	Reps (SJ)	Rest (SJ)	Total Sets
Base	4 large 3 small	3	10	1	3	10-12	1	21
Strength	3 large 2 small	4	6	3	3	8	2	18
Peaking	3 large 1 small	4	6-1	4	3	6	2	15

1. MJ = Multi joint
2. SJ = single joint
3. Large muscle groups e.g. chest, back, legs
4. Small muscle groups e.g. biceps, triceps
5. Rest between sets in minutes

Table V-23: **Frequency: Strength**

Day	Week 1	Week 2	Week 3	Week 4
Monday	Chest	Legs	Chest	Legs
Tuesday	Shoulders, Triceps	Back, Biceps	Shoulders, Triceps	Back, Biceps
Wednesday	Legs	Chest	Legs	Chest
Thursday	Back, Biceps	Shoulders, Triceps	Back, Biceps	Shoulders, Triceps
Friday	Chest	Back, Biceps	Chest	Back, Biceps
Saturday	Shoulders, Triceps	Legs	Shoulders, Triceps	OFF
Sunday	OFF	OFF	OFF	OFF

Table V-24: **Acute Variables: Cardiovascular**

Type workout /Phase	**Base Phase 4-8 weeks**	**Stamina Phase 4 weeks**	**Speed/Peaking Phase 4 weeks**
Monday	Tempo Run (5) increasing from 2@80% to 4 miles @ 85% RRHR	Tempo Run (5) 4 miles @ 85% RRHR	Tempo Run (5) 4 miles @ 85% RRHR
Tuesday	Bike: (Aerobic Capacity Intervals) increasing from 3-6 sets of 3:00 min at 85% RRHR	Bike: Aerobic Conditioning 45 min @ 55-65% RRHR	Bike: Aerobic Conditioning 45 min @ 55-65% RRHR
Wednesday	Fartlek Run increasing from 2-4: ½ mile pick ups @ 80-85%. The base running is at @ 55-65% MHR	Aerobic Capacity Intervals: 220, 440 warm ups and 880 intervals building to 6-8x880 @ 90% RRHR	Aerobic Capacity Intervals: same as stamina decreasing to 2x880 and adding anaerobic intervals building to 4 (110m) @ 95%
Thursday	OFF	OFF	OFF
Friday	Run: Aerobic Conditioning increasing from 3-6 miles @ 55-65 % RRHR	Run: Aerobic Conditioning 3 miles @ 55-65 % RRHR	Run: Aerobic Conditioning 3 miles @ 55-65 % RRHR
Saturday	Run: Aerobic Conditioning (Long) increasing from 8-10 miles @ 55-65% RRHR. Every 4th week is OFF	Run: Aerobic Conditioning (Long) alternating 6/8 miles @ 55-65% RRHR. Every 4th week is OFF	Run: Aerobic Conditioning (Long) alternating 6/8 miles @ 55-65% RRHR with the 4th week off
Sunday	OFF	OFF	OFF
Total Intensity Mileage	None above 85% RRHR	Building from 8-9% the first week to 10% the last week none above 90% RRHR	Decreasing to 8%. 880's remain at 90% and 110's increase to 95% RRHR
Total Running Mileage	Increasing to 30 over 4 weeks or 40 over 8 weeks (10%/week)	22-28 miles/week depending on length of base phase	Run 18-24 miles/week.

1. RRHR = Reserve/Resting Heart Rate calculated with Karnoven Method
2. Assumes a base of 20 miles / week before starting base phase

SECTION VI: DETRAINING: TRAINING ON LIMITED TIME

The program outlined above incorporates 11 workouts a week, which take about 1.5 hours a day on most days. Most people are probably not willing or able to commit this amount of time to a workout program. This chapter will use the principles outlined above to construct the optimum program for one hour a day, 5-6 days a week.

1. CARDIOVASCULAR TRAINING

a. Intensity

Detraining studies unanimously indicate that intensity not duration is key to sustaining performance during periods of reduced training.

Hickson, et al studied the effects of both reduced training duration and reduced training intensity in previously trained subjects. In both studies, subjects participated in an intense cycling and running program for 10 weeks. The training was performed 40 minutes a day, 6 days a week, and consisted of intervals on a cycle ergometer and continuous running. Following the training period, both studies studied the results of 15 weeks of detraining where intensity and frequency remained constant, but duration was reduced by one-third or two-third. [232]

In the reduced duration program two groups continued to train for 26 and 13 minutes a day. This corresponded to one-third and two-third reductions. Calculated left ventricular mass increases 15-20% after training and remained elevated during de-training. VO2max increased 10-20% during training and did not change during the detraining. Short-term endurance was measured by running and cycling at maximal work rates that resulted in exhaustion in 4-8 minutes. Short-term endurance remained

the same in both reduced duration groups after 15 weeks of reduced training. Long term endurance, as measured by cycling to exhaustion at 80% of VO2max increased by more than two-fold during training. Interestingly, after 15 weeks of detraining, the one-third reductions group showed no loss in long term endurance. The two-thirds reduction group, however showed a significant loss in long term endurance.[233]

In a companion study of reduced training intensity, Hickson et al , similar groups executed an identical training program followed by 15 weeks of reduced intensity. Duration and Frequency were held constant, but work load was reduced by one-thirds and two thirds respectively. On the cycle, the pedal resistance was reduced and in running workouts, the speed was reduced.[234]

The results indicated that intensity is much more significant in maintaining cardiovascular performance. As in the reduced duration study, left ventricular mass increased by about 15%, but with reduced intensity, it returned to control levels in both groups. VO2max increased from 11-20% after 10 weeks of training, In the one-thirds reduction group, VO2max was significantly lower after 10 and 15 weeks of reduced training, but still slightly higher than pre-training level. In the two-thirds reduction group, significant decline was evident after only 5 weeks and remained low through 15 weeks. In running, the 15-week VO2max was actually lower than pre-training level. [235]

The significance of these two studies is that in situations of reduced training, it is more important to retain intensity than duration. The exception being long term endurance to exhaustion. The two most important forms of intensity are lactate threshold runs and intervals. Advice from coaches supports the contention that one of

each of these in a 7-day microcycle is adequate to maintain or slightly improve cardiovascular performance.

b. Duration

For maintenance of long term endurance, duration appears to be important. Dudley et al found that longer exercise bouts produce greater increases in mitochodrial density, however there is a point of diminishing returns (see figure 1). It is important to note that after 1 week of detraining, almost 50% of the increase in mitochodrial content were lost. After 5 weeks all of the adaptations had been lost (see figure 2).[236] The significance of this finding is that to maintain the full range of cardiovascular capability an athlete must devote at least one day in each microcycle, to a long run. Advice from running coaches supports this evidence.

The significance of this finding is that an athlete must maintain at least one longer run each week to sustain the mitochondrial content of the muscle fibers.

c. Frequency

The American College of Sports Medicine recommends training cardiovascular systems 3-5 days each week. If you only have a limited amount of time to devote, then each workout must have a specific purpose.

The evidence clearly supports 3 specific workouts over 7 days; one long run to maintain long term endurance, one lactate threshold run to maintain endurance at the anaerobic threshold, and one day of intervals to maintain anaerobic glycolysis and recruitment of type 2 fibers.

2. STRENGTH TRAINING

a. Acute Variables

The application of the acute variables will not change with the reduction in frequency. A proven formula is a periodized program using at least 3 sets, varying the number of repetitions and resistance by mesocycle. Those recommendations are covered in the section on Strength Training.

b. Frequency

To a great degree, the frequency of workouts depends on the experience and recoverability of the lifter. Early studies and the current guidelines from the American College of Sports Medicine all indicated that 3 days of lifting, with a day of rest between each workout allowed adequate recovery for novice lifters and produced strength gains.

What the studies are really saying is that a muscle can be trained every other day. Once resistance workouts reach a high level of intensity, then more than 48 hours is appropriate between workouts. Muscles gain strength and size during the rest period between exercise periods. This does not mean that another muscle cannot be worked while one is resting.

McCarthy et al cited significant results from a 6 workout per week format (3 cardiovascular and 3 strength).[237] Hunter et al proved that 8 workouts (4 cardiovascular and 4 strength) a week over 6 days was also effective.[238] These studies provide a framework for training options. Both 3 and 4 days a week are proven to be effective when combined with cardiovascular training. The optimum frequency per

muscle group appears to be 1.5 –2 times per week when combined with high intensity cardiovascular exercise.

3. RECOMMENDATION

Table V-25: **Periodization**

	Mesocycle 1: (4-8 weeks)	**Mesocycle 2: (4 weeks)**	**Mesocycle 3: (4 weeks)**
Aerobic	Base Phase	Stamina Phase	Peaking Phase
Strength	Hypertrophy Phase	Strength Phase	Peaking Phase

Table V-26: **Schedule**

Week / Day	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Monday	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps
Tuesday	Run: Tempo	Run: Tempo	Run: Tempo	Run: Tempo
Wednesday	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps
Thursday	Intervals	Intervals	Intervals	Intervals
Friday	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps
Saturday	Run: Long	Run: Long	Run: Long	OFF
Sunday	OFF	OFF	OFF	OFF

Table V-27: **Acute Variables: Strength**

Phase	Exercises/ muscle group	Sets (MJ) per exercise	Reps (MJ)	Rest (MJ)	Sets (SJ) per exercise	Reps (SJ)	Rest (SJ)	Total Sets
Base	3 large 3 small	3	10	1	3	10-12	1	18
Strength	3 large 2 small	3	6	3	3	8	2	15
Peaking	3 large 1 small	3	6-1	4	3	6	2	12

1. MJ = Multi joint
2. SJ = single joint
3. Large muscle groups e.g. chest, back, legs
4. Small muscle groups e.g. biceps, triceps
5. Rest between sets in minutes

Table V-28: **Frequency: Strength**

Day	Week 1	Week 2	Week 3	Week 4
Monday	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps
Tuesday	OFF	OFF	OFF	OFF
Wednesday	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps
Thursday	OFF	OFF	OFF	OFF
Friday	Chest, Shoulders, Triceps	Legs, Back, Biceps	Chest, Shoulders, Triceps	Legs, Back, Biceps
Saturday	OFF	OFF	OFF	OFF
Sunday	OFF	OFF	OFF	OFF

Table V-29: **Acute Variables: Cardiovascular**

Type workout /Phase	Base Phase 4-8 weeks	Stamina Phase 4 weeks	Speed/Peaking Phase 4 weeks
Monday	OFF	OFF	OFF
Tuesday	Tempo Run (5) increasing from 2@80% to 4 miles @ 85% RRHR	Tempo Run (5) 4 miles @ 85% RRHR	Tempo Run (5) 4 miles @ 85% RRHR
Wednesday	OFF	OFF	OFF
Thursday	Fartlek Run increasing from 2-4: ½ mile pick ups @ 80-85%. The base running is at @ 55-65% MHR	Aerobic Capacity Intervals: 220, 440 warm ups and 880 intervals building to 6-8x880 @ 90% RRHR	Aerobic Capacity Intervals: same as stamina decreasing to 2x880 and adding anaerobic intervals building to 4 (110m) @ 95%
Friday	OFF	OFF	OFF
Saturday	Run: Aerobic Conditioning (Long) increasing from 8-10 miles @ 55-65% RRHR. Every 4th week is OFF	Run: Aerobic Conditioning (Long) alternating 6/8 miles @ 55-65% RRHR. Every 4th week is OFF	Run: Aerobic Conditioning (Long) alternating 6/8 miles @ 55-65% RRHR with the 4th week off
Sunday	OFF	OFF	OFF
Total Intensity Mileage	None above 85% RRHR	Building from 8-9% the first week to 10% the last week none above 90% RRHR	Decreasing to 8%. 880's remain at 90% and 110's increase to 95% RRHR
Total Running Mileage	Increasing to 24 over 4 weeks or 30 over 8 weeks (10%/week)	18-24 miles/week depending on length of base phase	Run 16-21 miles/week.

1. RRHR = Reserve/Resting Heart Rate calculated with Karnoven Method
2. Assumes a base of 20 miles / week before starting base phase

Word Count: 21,497

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